INFLUENCE OF CURCUMIN ON GROWTH PERFORMANCE AND IMMUNE STATUS OF NURSERY PIGS

By

MEGAN RENÉ BIBLE

Bachelor of Animal Science
Oklahoma State University
Stillwater, Oklahoma
2005

Master of Science
Oklahoma State University
Stillwater, Oklahoma
2009

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INFLUENCE OF CURCUMIN ON GROWTH PERFORMANCE AND IMMUNE STATUS OF NURSERY PIGS

Dissertation Approved:

Dr. Scott D. Carter

Dissertation Adviser

Dr. Jennifer Hernandez Gifford

Dr. Clint Krehbiel

Dr. Keith Bailey

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Abstract: Five experiments were conducted to determine the effects of curcumin on growth performance and immune response of pigs. Experiment one evaluated the effects of increasing levels of turmeric on growth performance and immune response of nursery barrows. Increasing levels of turmeric powder quadratically increased final BW, ADG, and ADFI, and linearly increased G:F when compared to a control diet containing no antibiotics. Turmeric decreased the change in TNF-α at h 3 PI (post-injection) compared to the control diet. The second experiment was to determine the effects of curcumin supplementation vs. carbadox on growth performance and immune status of nursery pigs. Pigs fed 46 mg/kg of curcumin had similar final BW, ADG, ADFI, and G:F as pigs fed 55 mg/kg of carbadox. Curcumin had the lowest change in TNF-α at h 3 PI. Experiment three was a two-part study that examined the effects of increasing levels of curcumin on growth performance and immune status of nursery pigs. Pigs fed increasing levels of curcumin had similar growth performance when compared to pigs fed the antibiotic in study 1. Curcumin decreased the change in TNF-α at h 3 PI. However, in study 2, pigs fed increasing levels of curcumin had decreased final BW, ADG, and G:F when compared with the antibiotic. Pigs fed curcumin had similar TNF-α concentrations compared with pigs fed the antibiotic. Experiment four evaluated the long-term effects of increasing levels of curcumin on growth performance and carcass characteristics of finisher pigs. There were no differences observed in growth performance, carcass, or meat quality characteristics in pigs fed curcumin compared with pigs fed an antibiotic. The last experiment was to determine the potential for increasing soybean meal usage in diets of weanling pigs fed curcumin. Curcumin numerically increased final ADG and ADFI, but had no effect on fecal consistency of nursery pigs. The 30% soybean meal-based diet decreased ADG, ADFI, and G:F for d 0-21 and decreased fecal consistency. In conclusion, these results suggest that 46 to 94 mg/kg of curcumin in the diet maximizes growth performance and improves immune response and may have the potential to replace antibiotics in feed.

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CHAPTER I

INTRODUCTION

Weaning of pigs occurs at 21 days of age or earlier. Early weaning is performed to increase productivity of the sow and to aide in the reduction of disease transfer from sow to pig (Maxwell and Carter, 2001). However, at this time, the mother is at her peak milk production and the pigs are consuming more milk than creep feed. The abrupt change in diet, from milk to dry feed, produces negative intestinal changes in the pig, which leads to post-weaning lag (PWL) or post-weaning growth check (Mahan and Lepine, 1991; Pluske et al., 1997; Nabuurs, 1998; Lallès et al., 2007a). Besides dietary changes, environmental and social stress contributes to post-weaning lag. Mixing of littermates, moving to a new barn, and establishing social hierarchies are a few of the latter two stressors a newly weaned pig will encounter (Spreeuwenbertg et al., 2001; Lallès et al., 2007a; van der Meulen et al., 2010).

A consequence of PWL is low voluntary feed intake, which occurs due to the abrupt diet change. Low feed intake will cause a reduction in growth and performance, an increased chance of disease, and diarrhea (Lallès et al.,

2007a). It has been suggested that weaning is the most stressful period for a pig (Moeser et al., 2007).

A common method of decreasing post-weaning lag is the complexity of the diets fed to the pigs. The diets are considered to be high nutrient dense diets (HNDD). As the commercial industry has moved towards weaning pigs at earlier ages, the complexity of the diets have to be increased in order for the pigs to grow and meet their requirements. The younger the pig is when weaned the more complex the diet needs to be (Nelssen, 1986; Maxwell and Carter, 2001). However, these HNDD are very expensive. Therefore, adapting the pigs to a less complex, cheaper diet is a must in the commercial industry. Nursery pigs are fed on a phase feeding program where complexity of diet decreases with each phase. Many farms use a four-phase feeding program, but programs can fluctuate between three and six phases (De Rouchey et al., 2010).

A supplement in HNDD to help alleviate the effects of post-weaning lag in pigs is subtherapeutic antibiotics. Use of subtherapeutic antibiotics or growth-promoting antibiotics is more effective for young pigs than older swine. One way antibiotics increase growth in nursery pigs is by improving performance, when feed intake is constant. Antibiotics also improve protein and nitrogen metabolism (Gaskins et al., 2002). The increase in performance is greater in the commercial industry than in a research (university) setting. Besides increasing growth, antibiotics decrease mortality in young pigs (Cromwell, 2001). Recent research has shown that antibiotics in feed do not have the response it did 20 plus years ago. Jacela et al. (2009) reported an improvement of 5.2% and 1.4% in average

daily gain and feed efficiency, respectively, in a commercial setting when subtherapeutic antibiotics are fed. The reasoning behind this is due to the improved biosecurity changes the swine industry has implemented (Jacela et al., 2009).

Despite the positive effects of subtherapeutic antibiotics, antibiotic use is a concern due to antibiotic resistant bacteria. It is estimated in the United States alone antibiotic-resistant bacteria have a yearly impact of $5-$24 billion (Ahmad et al., 2011). Subtherapeutic antibiotic use has been a concern since 1969 when a report by the Swann Committee was given to the English Parliament, to now, where some countries, like the European Union, have banned subtherapeutic antibiotics (Hogberg et al., 2009). As one knows, consumer perception is everything; therefore, the use of antibiotics in feed may eventually be banned in the United States.

With a growing concern of antibiotic-resistant bacteria, the subtherapeutic antibiotic usage in feeds is starting to decrease, especially in the swine industry. There have been numerous feedstuffs studied to replace or reduce antibiotics in feed. Some of the supplements explored are acids, direct-fed microbials, enzymes, spray-dried plasma, enzymes, and essential oils (Turner et al., 2001; Pettigrew, 2006). However, the results are variable in improving growth performance in nursery pigs, especially when the supplements are compared to subtherapeutic antibiotics.

The use of complementary and alternative medicine (CAM) is becoming a popular alternative medicine, with an estimated 50% of the human population using alternative medicine. A 300% increase in use of herbal medicine was observed from 1990 to 1997 (Reddy et al., 2013). With the rise in human population and the greater demand of organic products in livestock production, herbal use in the livestock industry is beginning to occur. A popular CAM product that has been used for decades and a possible supplement for livestock is turmeric.

Turmeric, *Curcuma longa* Linn, is an herbaceous spice used in Southeast Asian countries (Tayyem et al., 2006; Bengmark et al., 2009) and is part of the ginger family or Zingiberaceae (Brewer, 2011). Currently, turmeric is approved as a food additive, where it is used as a preservative and coloring agent in many foods (Tayyem et al., 2006; Bengmark et al., 2009). Turmeric has a bitter, tart taste and a spicy, aromatic aroma (Esatbeyoglu et al., 2012). Curcumin, demethoxycurcumin (DMC), and bisdemethoxycurcumin (BDMC) are the major non-volatile, fat soluble, polyphenolic compounds or curcuminoids and are the major components in turmeric (Zhang et al., 2010; Brewer, 2011).

Giving turmeric its characteristic yellow color and the most active component is curcumin or 1,7-bis (4-hydroxy-3-methoxyphenol)-1,6-heptadiene-3,5-dione (Lantz et al., 2005; Bengmark et al., 2009). Curcumin has been shown to decrease tumor necrosis factor-alpha (TNF-α), interferon-γ (IFN-γ), and cyclooxygenase (COX), suppress NF-κB activation, and to impede inducible nitric oxide synthase (iNOS) and vascular endothelial growth factor (VEGF), C-reactive

protein (CRP), and prostaglandin E2 (Rajasekaran, 2011). Besides having antimicrobial and antioxidant effects, curcumin has been shown to be a chemopreventative and be hypolipidemic (Tayyem et al., 2006). In humans, curcumin has helped alleviate symptoms associated with Crohn's disease, cancer, ulcerative colitis, gastric ulcer, peptic ulcer, atherosclerosis, irritable bowel syndrome, and gastric inflammation (Gupta et al., 2013).

Therefore, turmeric and/or curcumin have the potential to improve growth performance and immune status in pigs due to their pleiotropic properties. A series of five experiments were conducted to determine the effects of turmeric and curcumin in pigs. One set of experiments was conducted to establish the effects of curcumin and turmeric on growth performance and response to an innate immune challenge in nursery pigs. Another set of experiments investigated the effects of curcumin on long-term feeding of curcumin on growth performance, carcass characteristics, and meat quality characteristics in finisher pigs and to study the effects of supplementing curcumin in nursery pigs with a gastrointestinal disturbance.

CHAPTER II

REVIEW OF LITERATURE

POST-WEANING LAG AND DIARRHEA IN NURSERY PIGS:

Natural weaning of pigs occurs between 4 and 5 months of age. At this time, the pigs would be entirely established on a solid diet (Weary et al., 2008). Before the times of early weaning, commercial pigs were weaned from their mothers at approximately 10-12 weeks of age (Nabuurs, 1998; Castillo et al., 2007). At this stage, the pigs were consuming more creep feed than milk and the mother was at the point of producing small amounts of milk. Now, the weaning process occurs at roughly 21 days of age or earlier. The reasoning behind an earlier weaning age is to increase the productivity of the sow and reduce disease transfer from sow to pig (Maxwell and Carter, 2001). However, the mother is at her peak milk production and the pigs are consuming more milk than creep feed. This abrupt change in diet, milk to dry feed, causes negative intestinal changes to occur in the pig, which leads to post-weaning lag (PWL) or post-weaning growth check (Mahan and Lepine, 1991; Pluske et al., 1997; Nabuurs, 1998; Lallès et al., 2007a). Besides dietary changes, environmental and social stress contributes to post-weaning lag. Mixing of littermates, moving to a new barn, and establishing social hierarchies are a few of the latter two stressors a newly-

weaned pig will encounter (Spreeuwenbertg et al., 2001; Lallès et al., 2007a; van der Meulen et al., 2010). A low voluntary feed intake due to the abrupt change in diet results in a reduction in growth and performance, an increased chance of diseases, and diarrhea (Lallès et al., 2007a). It has been suggested that weaning is one of the most, if not the most, stressful period for a pig (Moeser et al., 2007). Most of the changes that occur in pigs after weaning will be discussed further in this section.

GASTROINTESTINAL HEALTH

The intestinal morphology of newly weaned pigs plays a vital role. The gastrointestinal tract is involved in many functions, such as, nutrient, water, and electrolyte absorption, as well as, mucin and immunoglobulin secretion (Lallès et al., 2004). The intestinal barrier is the first line of defense against potential pathogens, toxins, and foreign antigens. A single layer of columnar epithelial tissue comprises the barrier. After weaning, pigs can have an intestinal barrier breakdown. A characteristic breakdown will increase permeability allowing for antigenic agents, such as toxins and bacteria, to gain access to the subepithelial tissues. This “leaking” of antigens leads to malabsorption, diarrhea, inflammation, and a possible systematic disease (Moeser et al., 2007). Usually, the first meal for 50% of newly-weaned pigs is consumed by 24 hours after weaning (Lallès et al., 2004), but there is not enough diet consumed to meet the energy requirements of the pig. During the first 48 hours, an estimated 10% of nursery pigs do not consume any feed and the others have a very low feed (low energy) consumption (Lallès et al., 2004; Wijtten et al., 2011). Therefore, it has

been stated that the weaned pig needs 3 days after weaning to meet energy maintenance requirements and 8 to 14 days to consume pre-weaning energy quantities (Lallès et al., 2004). Since there is low intake of feed, the energy requirements are not met. In fact, the pigs are in a negative energy balance the first 4 to 6 days after weaning (Le Dividich and Herpin, 1994). This energy depression leads to an impaired gastrointestinal (GI) tract (van der Meulen et al., 2010). The act of weaning can lead to morphological, microbial, and enzymatic changes in the GI tract. All of these changes can lead to an impaired gastrointestinal tract.

Morphological Changes

Many researchers have investigated the impact of weaning on gut morphology (Pluske et al., 1997; Nabuurs, 1998; Gu et al., 2002; Castillo et al., 2007; Miller et al., 2007; Lackeyram et al., 2010; Thomson and Friendship, 2012). Most changes in gut physiology will occur during the first 2 weeks of weaning (Lallès et al., 2007a). It has been reported that a decrease in feed intake will decrease villi height in the small intestine, especially in the proximal jejunum. Weaning will shorten villi height and increase crypt depth, which is diet dependent and independent (Pluske et al., 1997; Lallès et al., 2004; Lackeyram et al., 2010; Thomson and Friendship, 2012). Four to seven days post-weaning, villi height is decreased by 30-40% (Thomson and Friendship, 2012). When pigs are weaned at 21 days of age, the villi height was decreased by 75% within 24 hours after weaning (Pluske et al., 1997). However, it can be reestablished by day 14. In addition to a shorter villus height, the microvilli of weaned pigs are

reduced between 3 to 7 days post-weaning (Thomson and Friendship, 2012). This decrease in villi height and increase in crypt death leads to a decrease in digestion and absorption of nutrients. There are less enterocytes present in the gastrointestinal (GI) tract for absorption because of the decrease in villi height. More immature enterocytes are being regenerated, which is why there is an increase in crypt depth (Pluske et al., 1997; Kitt et al., 2001). A positive correlation between voluntary feed intake during the first week of post-weaning and villi height has been reported, the higher the feed intake the longer the villous (Lallès et al., 2007a; Verdonk et al., 2007). Data suggests that pigs with diarrhea have a short villus height and a deep crypt depth when compared to pigs without diarrhea (Nabuurs, 1998). In addition, Nabuurs (1998) reported that in pigs that died from diarrhea, their crypt depth was even deeper and villus height even shorter than the pigs that had diarrhea.

The small intestine is not the only part of the GI tract that suffers due to weaning. When suckling (S) pigs are compared to weaned (W) pigs (one week after weaning), the pH of the cecum and colon was lower in the W pigs. The W pigs had a numerically shorter crypt depth and a lower crypt density. The S pigs had a greater number of Goblet cells and lower numbers of intraepithelial lymphocytes and mitotic cells than the W pigs. Therefore, weaning causes an increase in the mucosal immune system and proliferation activities (Castillo et al., 2007). Rearing environment does not seem to have an influence on gut morphology. Miller et al. (2007) reported that outside reared pigs do not have a more developed GI tract than inside reared pigs after weaning. However, the

outdoor-weaned pigs were heavier than the indoor-reared pigs (Miller et al., 2007).

Microbial Changes

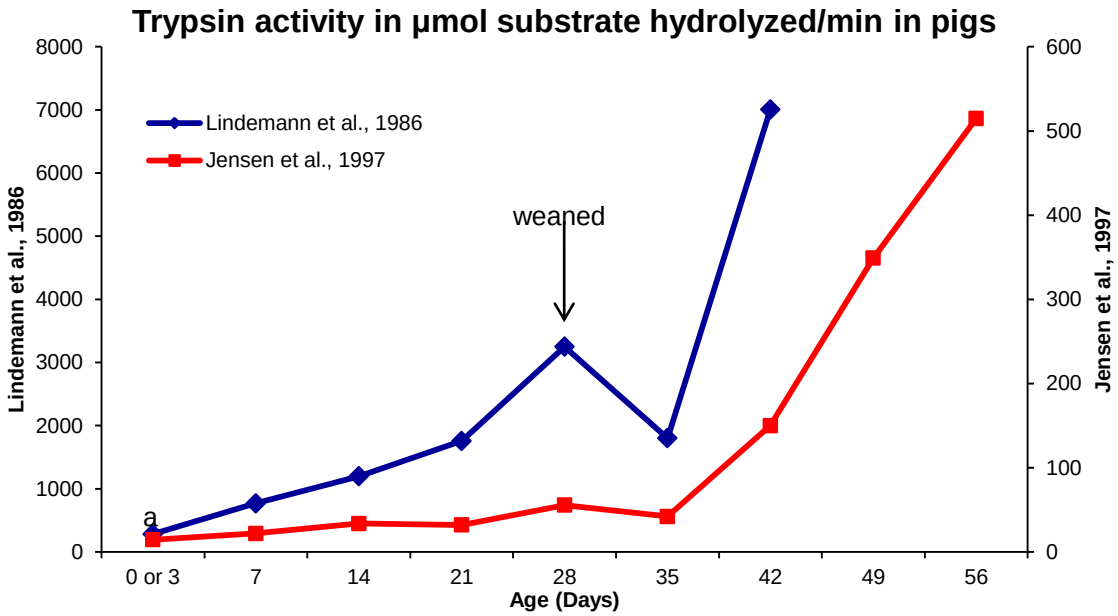
Natural weaning occurs over an approximately 4 to 5 month period. During this time, the gastrointestinal tract has the capability to adapt slowly to less milk and a more solid diet. However, in the commercial industry, this change occurs over an abrupt couple of days. This drastic change causes a disbiosis, or microbial imbalance, in the intestine (Pluske et al., 2002; Lallès et al., 2007a). Suckling pig GI microbiota is established by their surrounding environment and mother (Lallès et al., 2007a). In fact, the microflora of the pig's GI tract is established approximately 48 hours after birth. Most of the establishment is due to consumption of the sow's feces (Pluske et al., 2002). Lactic acid bacteria, enterobacteria, and streptococci are the first groups of bacteria to establish in the GI tract of the suckling pig (Lallès et al., 2007a). The predominant bacteria present in suckling pigs in the stomach and small intestine are lactobacilli and streptococci. However, the major groups of bacteria that have been anaerobically isolated from the pig GI tract are: *Acidodaminococci*, *Bacteriodes*, *Clostridia*, *Enterobacteria*, *Eubacteria*, *Fusobacteria*, *Lactobacillus*, *Megasphera*, *Mitsuokella*, *Prevotella*, *Selenomona*, and *Streptococcus* (Pluske et al., 2002). After weaning, the presence of lactobacilli drops drastically. In particular, *Lactobacillus acidophilus*, *L. reuteri*, and *L. sobrius* were stable before weaning, but after weaning these bacteria dropped considerably in numbers (Lallès et al., 2007b). Castillo et al. (2007) reported cecal changes that occur

after weaning. When compared to suckling pigs of the same age, 1 week old weaned pigs had a decrease in lactobacilli:enterobacteria ratio. This would be considered a negative effect due to lower numbers of lactobacilli. High lactobacilli numbers indicate a more robust GI tract (Castillo et al., 2007).

Enzymatic Changes

Changing the diet from a milk-based (liquid) diet to a solid diet causes drastic changes in enzyme production in the GI tract of the newly-weaned pig. The pig, as mentioned earlier, consumes very minuscule amounts of feed during the first week after weaning. The depressed feed intake, change in type of diet consumed, and other weaning stressors produces a decrease in enzyme secretion in the GI tract. Numerous research has been conducted showing the changes in enzyme secretion before and after weaning (Shields et al., 1980; Lindemann et al., 1986; Owsley et al., 1986; Jensen et al., 1997). The composition of the diet goes from a high fat diet (sow milk) to a high carbohydrate diet (Spreeuwenberg et al., 2001). This change in diet is what causes the enzymatic changes. Figures II.1-4 provide an illustration of the decline of the expression of the enzymes trypsin, chymotrypsin, amylase, and lipase before and after weaning. The digestion of fat in sow's milk from a suckling pig is 98%, whereas, when compared to a weanling pig, fat digestion decreases to 65-80%. Some of this change in digestion is due to a decrease of the lipolytic enzymes colipase, lipase, and carboxyl ester hydrolase after weaning (Jensen et al., 1997).

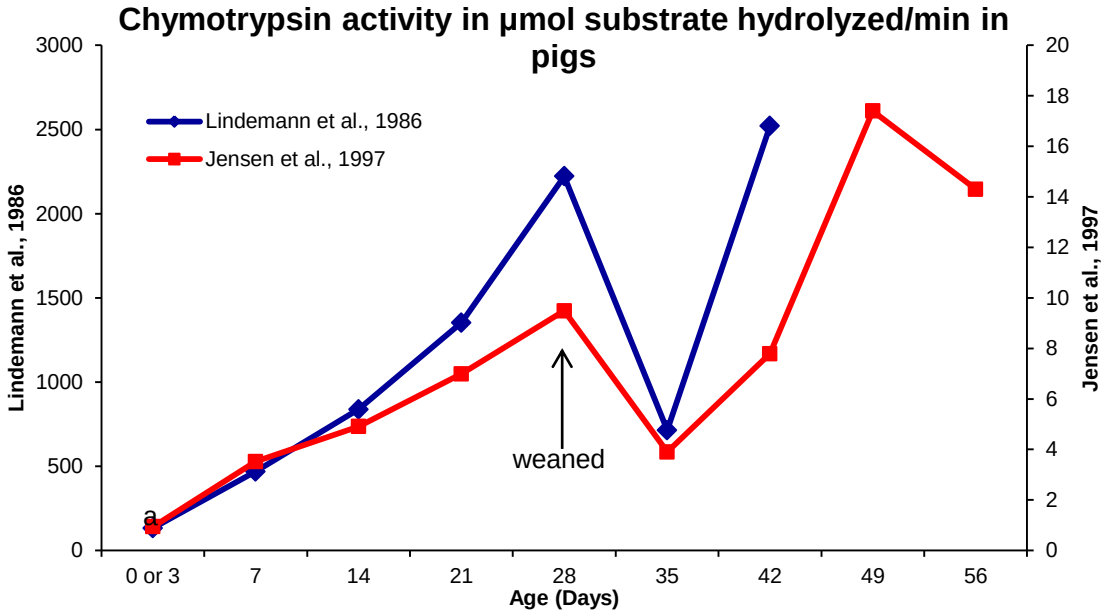
Figure II.1 Trypsin activity in pigs before and after weaning (at 28 days of age)



[a]Lindemann et al., 1986 begin analysis on day 0 and Jensen et al., 1997 was on day 3

(Adapted from Lindemann et al., 1986; Jensen et al., 1997)

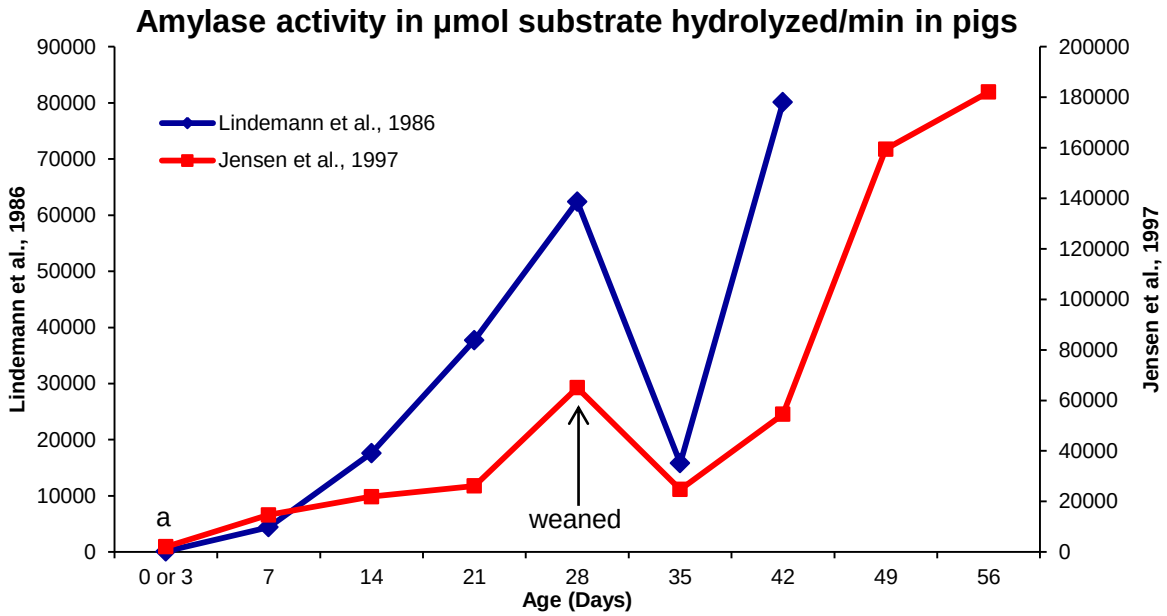
Figure II.2 Chymotrypsin activity in pigs before and after weaning (at 28 days of age)



[a]Lindemann et al., 1986 begin analysis on day 0 and Jensen et al., 1997 was on day 3

(Adapted from Lindemann et al., 1986; Jensen et al., 1997)

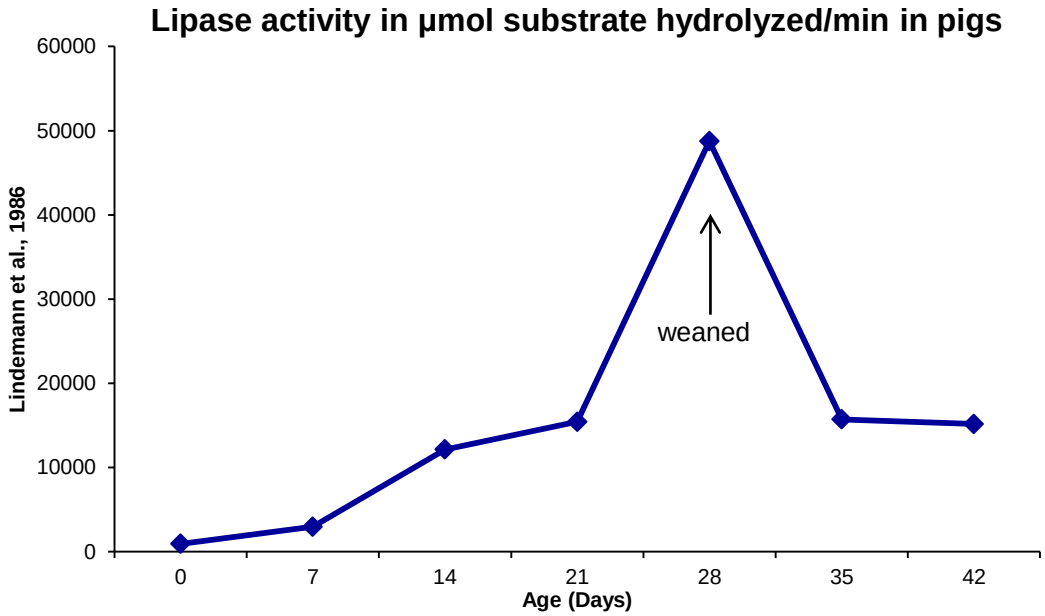
Figure II.3 Amylase activity in pigs before and after weaning (at 28 days of age)



[a]Lindemann et al., 1986 begin analysis on day 0 and Jensen et al., 1997 was on day 3

(Adapted from Lindemann et al., 1986; Jensen et al., 1997)

Figure II.4 Lipase activity in pigs before and after weaning (at 28 days of age)



(Adapted from Lindemann et al., 1986)

OTHER STRESSORS

There are other stressors that aid in decreasing growth performance after weaning. Some of these stressors include age of weaning, hormonal changes, and dietary composition of the nursery diets. Most newly-weaned pigs are weaned from their mother at ~21 days of age, transported on a semi-trailer, placed in pens with non-littermates, which leads to fighting over dominance, and offered a completely different diet.

Weaning Age, Weaning Weight, and Time of Weaning

Mahan and Lepine (1991) studied several factors that influence PWL, which were farrowing conditions, weight at weaning, and feeding program. Pigs weighing less than 5.0 kg at weaning and fed a high nutrient dense diet (HNDD) had a more depressed growth performance, as well as, took longer to reach market weight than the heavier pigs at weaning, whereas pigs that are heavier at weaning may have a more developed GI tract, thus having the capability to better cope with PWL (Mahan and Lepine, 1991).

Age of weaning has an impact on PWL. In a review article by Weary et al. (2008), numerous studies reported that weaning age has an impact on growth performance because of feed intake. It was stated the older the pig at time of weaning the higher the feed intake (Weary et al., 2008). In a study conducted by Leibbrandt et al. (1975), pigs weaned at 4 weeks of age had a quicker response in gain and feed intake than the other two groups (weaned at 2 and 3 weeks of age) of pigs. However, when the 3 different weaned ages were compared, all

groups were of similar body weight at 6 weeks of age (Leibbrandt et al., 1975). Some of these differences observed could be due to heavier weaning weight as observed in Mahan and Lepine (1991). Fangman et al. (1996) also reported similar results with weight and age at weaning. The older-weaned pigs had a higher ADG than the younger-weaned pigs, but it was stated that the difference might be related to weaning weight and not age (Fangman et al., 1996).

Dunshea et al. (2002) studied the effects of age, sex, and weaning weight on immediate and lifetime performance. The immediate effects on performance were influenced by weaning weight and age at weaning. The heavy weight pigs gained more weight than the light weight pigs after weaning. The pigs weaned at 14 days of age consumed less and gained less than the pigs weaned at 28 days of age during the post-weaning period. Weight at weaning had an impact on lifetime performance. When overall performance (nursery to slaughter) was researched, pigs weighing more at weaning out-performed the lighter pigs at weaning. Therefore, during the lifetime of a commercial pig, the weight at weaning (probably the weight at birth) is one of the biggest influences on growth performance (Dunshea et al., 2002).

Time of day may have an influence on PWL. Ogunbameru et al. (1992) conducted a study based on time of day of weaning. In this study, pigs that were weaned later in the day (20:00) grew better than the pigs weaned in the morning (08:00) due to an increase in feed intake and gain. The difference in performance could be attributed to meeting their diurnal eating patterns (Ogunbameru et al., 1992).

Dietary Changes

A major effect on pigs after weaning is the dietary change. As mentioned early, the diet goes from an all liquid diet to a solid diet. Weaned pig will acquire diarrhea after consuming the solid diet and this is due to the rapid change in diet. In a review by Pluske et al. (1997), it was stated weaned pigs consuming a slurry diet had higher villous height when compared to pigs fed the dry version of the diet. In the same review, it was indicated when pigs were fed a slurry diet their gain and intake were 11% and 13% higher than pigs consuming a dry diet. It was suggested the increase in villous was due to the increase in feed (energy) intake (Pluske et al., 1997).

Soybean meal is a major player in causing some of the effects of PWL. Soybean meal (SBM) is the major protein source used in swine diets in the United States (U.S.; Song et al., 2010). Therefore, inclusion of SBM in nursery diets can have detrimental effects. Type III hypersensitivity is observed when feeding too much SBM to early-weaned nursery pigs (Li et al., 1991a). The sensitivity is related to the antigenic proteins that are present in SBM. The active proteins, glycinin and β-conglycinin, are the cause of the problem (Li et al., 1991b). Approximately two-thirds of the protein in SBM is composed of the latter two proteins. This protein source also contains inhibitors of the enzymes trypsin and chymotrypsin, which are Kunitz trypsin inhibitor (α-conglycinin) and the Bowman-Birk trypsin-chymotrypsin inhibitor. During the first month after weaning, more than 80% of deaths observed in nursery pigs are the result of diarrhea and it is believed some of this diarrhea is due to SBM in the diet. The

inclusion of SBM in the diet has shown to reduce villi height in the jejunum. It is believed that some of this is due to a reduction in feed intake (Dréau and Lallès, 1999).

Immunological Changes

After weaning, the pigs no longer have the immune protection that is provided by the sow's milk. When a pig is born, its immune system is not developed and is naïve to its surroundings. The complete maturation of a pig's immune system happens at roughly 1 month of age (Niekamp et al., 2006).

There are several factors where gene expression is changed after weaning. Weaning elucidates an increase in gene expression of pro-inflammatory cytokines, interleukins 1β (IL-1β) and 6 (IL-6) and tumor necrosis factor α (TNF-α). The act of weaning also reduces the expression of antimicrobial peptide PR-39 in the bone marrow in pigs. Lactoferrin, another antimicrobial peptide, demonstrated a decrease in expression in the duodenum after weaning (Lallès et al., 2007b).

A group of researchers studied the effects of photoperiod and age at weaning on immune status of pigs during weaning. Niekamp et al. (2006) studied 14, 21, and 28 days of age at weaning, as well as, the photoperiods long (16 h) and short (8 h) day. The nursery pig weaned at 14 and 21 days of age had higher lymphocyte proliferation, neutrophil counts, and phagocytosis than pigs weaned at 28 days of age. Optimal performance was seen in pigs exposed to a long photoperiod and weaned at 28 days of age. Possible explanations for

the increase in performance were an increase in feed intake, more energy (maintenance energy) used for growth than maintaining the immune system, or the longer photoperiod enhanced average daily gain (Niekamp et al., 2006).

Hormonal Changes

The abrupt change in diet may lead to hormonal changes. Research has suggested the presence of certain hormones in sow milk aids in GI health. These growth factors are present in the milk. Insulin-like growth factors I and II (IGF-I and II) and epidermal growth factor (EGF) positively affect the GI tract. One might wonder if these factors are active after ingestion, research has shown that EGF is still intact and active once it reaches the GI tract of the suckling pigs (Kitts et al., 2001).

It has been reported after weaning glucocorticoids may aid in increasing the metabolism of amino acids (glutamine, arginine, and citrulline) in the enterocyte. This may lead to an increase in GI tract enzymes that aid in the metabolism of the amino acids (Lallès et al., 2004). However, with a decrease in feed intake after weaning, growth hormone (GH) increases and serum IGF-I and IGF-II decrease (Kojima et al., 2007), thus a decrease in gut integrity.

Plasma cortisol and corticotropin-releasing factor are increased after weaning (van der Meulen et al., 2010; Wijtten et al., 2011). It has been suggested that these two hormones can initiate detrimental effects in the gastrointestinal tract of the nursery pig (van der Meulen et al., 2010). When compared to unweaned pigs of the same age, Moeser et al. (2007) reported an

increase in intestinal permeability in the jejunum and colon of weaned pigs. In the same study, it was concluded that weanling pigs had an increase in the expression of corticotrophin-releasing factor (CRF) receptor 1 in the colon and jejunum. It is believed that the intestinal dysfunction observed after weaning is due to the increase of the CRF receptors. The activation of the receptors occurs via the prostanoid and enteric nerves pathways (Moeser et al., 2007). Moeser et al. (2007) also reported that after weaning there was an increase in cortisol and CRF, suggestive of induced central stress pathways. The study discovered that CRF concentrations mirrored intestinal disturbances. Meaning, as CRF increased so did the intestinal disturbances. The cells that express the CRF receptors are unknown; therefore, more studies are needed (Moeser et al., 2007).

Kick et al. (2012) also reported an increase in plasma cortisol levels one day after weaning. It was stated cortisol levels were highest the day after weaning and by 6 days post-weaning the cortisol concentrations were returned to normal. This increase in cortisol levels was independent based on age. All pigs tested, which were weaned at 14, 21, and 28 days of age, had a drastic increase in cortisol (Kick et al., 2012). An increase in cortisol levels does indicate a stressful event, which in this case, would be the act of weaning the pigs.

DIARRHEA

Besides a reduction in growth performance, a primary sign of post-weaning lag is diarrhea. It has been reported that 32 to 76% of newly-weaned

pigs have diarrhea the first 2 weeks in the nursery (Bruins et al., 2011). Several factors, such as changes in the microbial population in the intestines, changes in the morphology of the intestines, nutritional changes, and changes in the functions of the intestines, lead to post-weaning diarrhea (PWD; Nabuurs, 1998; Bruins et al., 2011). Another change is the loss of antibodies from sow milk (Fairbrother and Gyles, 2012). One factor is the presence of several different organisms. *Escherichia coli* (*E. coli*) is the organism most associated with post-weaning lag diarrhea; however, other microorganisms such as, rotaviruses, *Serpulina hyodysenteriae*, and *Clostridium perfringens*, have been detected in nursery pigs with diarrhea. It is believed that the presence of one or more of these microorganisms cause, the sometimes fatal, PWD observed in weanling pigs (Nabuurs, 1998).

Post-Weaning Escherichia Coli Diarrhea

Numerous research has been conducted with pigs, diarrhea, and *E. coli* or post-weaning *E. coli* diarrhea (PWECD; Amezcua et al., 2008), or may also be referred to as post-weaning enteric colibacillosis (Montagne et al., 2004; Fairbrother and Gyles, 2012). The small intestine is usually affected by *E. coli* 3 to 10 days after weaning (Pluske et al., 2002). It was stated in a paper in 1994 that 11% of deaths in post-weaning pigs is due to diarrhea. Worldwide, 5 million pigs die due to enterotoxigenic *E. coli* (ETEC), and this bacteria is the most common enteric disease in pigs (Owusu-Asiedu et al., 2003). *Escherichia coli* is a facultative anaerobic, Gram-negative rod, belonging to the family *Enterobacteriaceae*. The *Escherichia* genus is named after Theodor Escherich,

a German pediatrician. The bacteria are normal inhabitants of the gastrointestinal tract and are known to cause many diseases, including gastrointestinal diseases. One way to group the species *coli* is by serotypes. There are currently 4 serotypes or antigens: somatic is O, capsular or microcapsular is K, flagellar is H, and fimbrial is F (Fairbrother and Gyles, 2012).

Diarrhea emerges because of a huge increase of fluid being excreted out of the gastrointestinal (GI) tract. This large amount of volume is due to one of two mechanisms. One way is the secretion of fluid into the lumen of the GI tract. The other method is that the bowel does not absorb or reabsorb the fluid. The toxins, discussed later in this section, secreted by *E. coli* lead to the fluid imbalance, thus causing diarrhea (Fairbrother et al., 2005). The clinical signs of diarrhea usually include the following: yellow to gray diarrhea, dehydration, and emaciation. The diarrhea can last up to five days. Most of the pigs may be affected for quite a few days (Fairbrother and Gyles, 2012). While others have reported that diarrhea could last between 4-14 days (Pluske et al., 2002). However, there are some pigs that die with no signs of diarrhea. These pigs will have fluid accumulation in their gastrointestinal tract and invasion of the blood and tissue (Fairbrother et al., 2005). The most common type of pathogenic *E. coli* that induces diarrhea in swine is the enterotoxigenic type (Nataro and Kaper, 1998; Fairbrother et al., 2005).

Diarrhea from ETEC is one of the most economically important swine diseases (Zhang et al., 2007). Actually, PWECD leads to 1.5-2% mortality in

pigs and up to 25% mortality if the pigs are not treated (Fairbrother and Gyles, 2012). In fact, the first enterotoxigenic *E. coli* was identified in pigs with diarrhea (Nataro and Kaper, 1998). Many of these ETEC are resistance to three or more of the following antibiotics, neomycin, apramycin, spectinomycin, and trimethoprim-sulfonamide; furthermore, they have the capability to survive at least 6 months if protected by feces (Fairbrother et al., 2005). Most of these bacteria are α-hemolytic (Fairbrother and Gyles, 2012). The main route of transmission is thru the fecal-oral route, as well as, via aerosol (Pluske et al., 2002). The bacterium has the capability to colonize a mucosal location, dodge the host's defense mechanisms, multiply, and inflict host damage. All diarrheagenic *E. coli* have the capability to attach to the gastrointestinal mucosal surface, in spite of, nutrient competition with the indigenous microflora and peristaltic movement (Nataro and Kaper, 1198). The presence of specialized fimbriae (specific adhesion factors) allows the bacterium to adhere to the mucosa of the small bowel (Nataro and Kaper, 1998; Frydendahl, 2002).

Fimbriae (fimbrial adhesions) and enterotoxins are the major virulence factors of ETEC. The fimbriae contribute to PWD by allowing attachment to the gastrointestinal epithelium and starting colonization. Disruption of the fluid homeostasis in the intestine is one of the main functions of the enterotoxins. The disruption leads to an over secretion of fluid that causes diarrhea (Zhang et al., 2007). The ETEC bacteria produce at least one of two toxins. These toxins are referred to as heat-stable (ST) enterotoxin and heat-liable (LT) enterotoxin and are known derivatives of the cholera toxin (Nataro and Kaper, 1998; Nagy and

Fekete, 2005). These enterotoxins are located in plasmids in ETEC (Fairbrother et al., 2005). The LT toxin is a large protein (88 kDa), whereas, the ST is a small peptide of approximately 11-48 amino acids (Nagy and Fekete, 2005). This feature allows for swift evolution of the toxins, but there is no research suggesting that evolution has occurred (Fairbrother et al., 2005).

The presence of one or both of these toxins is what elucidates diarrhea (Nataro and Kaper, 1998). It is suggested that LT not only has the function of an enterotoxin, but also as an adhesion factor (Fairbrother et al., 2005). There are two variants of LT, LTI and LTII (Fairbrother and Gyles, 2012). The ST has three variants, STa, EAST1, and STb. The enterotoxin STa is seldom the only toxin produced by ETEC in pigs with diarrhea. The EAST1 or enteroaggregative heat-stable toxin is part of the STa family and is usually associated with the F4 fimbria, especially ETEC that are of the O group 149, F4+, LT+, and EAST1+. The latter combination is commonly shared in porcine ETEC. If LT is present, STb is usually present as well because both genes are on the same plasmid. This enterotoxin is almost solely associated with swine ETEC (Fairbrother et al., 2005). Research has demonstrated that these toxins cause diarrhea by altering the electrolyte and water balance in the gastrointestinal tract (Frydendahl, 2002). The toxins work together to elicit diarrhea. The LT induces a secretion of sodium, chloride, and bicarbonate ions, as well as, water into the lumen of the GI tract. The ST aids in diarrhea by inhibiting the absorption of sodium and chloride ions from the lumen (Pluske et al., 2002).

However, before these toxins can cause damage, bacteria have to be able to adhere to the enterocyte. This is accomplished by the presence of fimbriae. The most common ETEC fimbrial types found in weanling pigs with PWECD are F4 and F18 (Frydendahl, 2002; Fairbrother et al., 2005). In fact, F4 (K88) was first explained in swine enteritis and dysentery in 1961 (Gaastra and Graaf, 1982). Depending on the literature some of the fimbriae were designated as K antigens or something else until a proper designation was assigned. Therefore, the following antigens are the same when studying the literature: F4 = K88, F5 = K99, F6 = 987P, and F17 = Fy/Att25 (Nagy and Fekete, 2005; Schroyen et al., 2012).

Frydendahl (2002) conducted research in Denmark on pigs with post-weaning diarrhea and identified that 92.7% of the ETEC strains contained the F18 or F4 genes. The fimbriae F18 is most commonly associated with diarrhea in nursery pigs, whereas, F4 fimbriae is associated with suckling and nursery pig diarrhea (Fairbrother et al., 2005; Schroyen et al., 2012). The F18 fimbriae usually express the toxin ST and does not normally produce the LT. It also has two variants, F18ab and F18ac. The association of PWD and the F18 fimbriae vary over time and location. Another factor is some pigs may lack the intestinal receptor for F18, which does not allow for colonization, and furthermore, absence of ETEC F18 diarrhea.

The F4 (K88) has three different variants, which are F4ab, F4ac, and F4ad with F4ac being the most common. All three fimbriae types bind to intestinal

mucus, intestinal epithelial cells, and red blood cells. The F4 fimbriae bind to carbohydrates on glycoconjugates on the latter cell types. Just like with the F18 fimbriae, some pigs do not have the receptor for F4. However, there are a few differences. A pig can either be susceptible to one of the variants, two of the variants, all three of the variants, or none of the variants (Fairbrother et al., 2005).

The receptors for the pigs are inherited through a simple way. The receptor allele is dominant. The F4 receptor is located on chromosome 13 and F18 is located on chromosome 6. The pigs only have to have one dominant copy of the allele to be susceptible to binding of the F4 or F18 (Fairbrother and Gyles, 2012). Now, early in life, the receptors for ETEC F4 may be detrimental to nursery pigs, but research on Swedish pigs demonstrates that later in life, during the finishing phase, the F4+ pigs may have an upper hand on F4- pigs. In this study, 2 different sets of pigs were utilized. In the first set, the nursery pigs with the F4 receptors had a lower weight gain than the pigs without the receptor. However, in the second set of pigs, there were no differences observed for weight gain. It was stated that this difference could be due to the frequency of diarrhea (ETEC) in set 1. Pigs of set 1 had a higher frequency of diarrhea, thus resulting in poorer performance. When both sets were combined, the pigs with the receptor had a higher lean gain than the pigs without the receptor during the finishing phase (Edfors-Lilja et al., 1986).

Fairbrother et al. (2005) reported in a review that the most common serotype in swine post-weaning diarrhea is O149. The O149 *E. coli* are most commonly F4+; however, the F18+ isolates are more of mixture of the O serogroups, O139, O138, O141, O147, and O157 (Fairbrother and Gyles, 2012). The most common ETEC that cause PWD in swine is listed in Table II.1 (Francis, 2002; Fairbrother et al., 2005). More current research conducted by Zhang et al.

Table II.1 Most common Enterotoxigenic *E. coli* O serogroups that cause post-weaning diarrhea in nursery pigs

O serogroup	**Associated fimbrial antigens**	**Associated H antigen**	**Toxin(s) produced**
8	F4ab (K88ab), F4ac (K88ac)	H19	LT, STb ± STa
138	F18, F4ac*	H–, H4	STa, STb
139	F18	H1	STa, STb
141	F18, F4ab, F4ac	H4	STa, STb
147	F4ac, F18	H6, H19	–
149	F4ac, F18*	H10, H19, H43, H–	LT, STb ± STa
157	F4ac	H19, H43	STa, STb ± STa

*Occasionally

(Adapted from Francis, 2002; Fairbrother et al., 2005)

(2007) in the U.S. is similar to the most common ETEC diarrhea. In this study, the majority of the fecal samples were from diarrheagenic nursery pigs from farms in Minnesota, Iowa, South Dakota, and North Dakota. The most common ETEC strains were the F4 (K88) and F18 fimbriae. The common combination of ETEC strains with toxins were K88/LT/STb, K88/LT/STb/EAST1, and F18/STa/STb/Stx2e (Zhang et al., 2007).

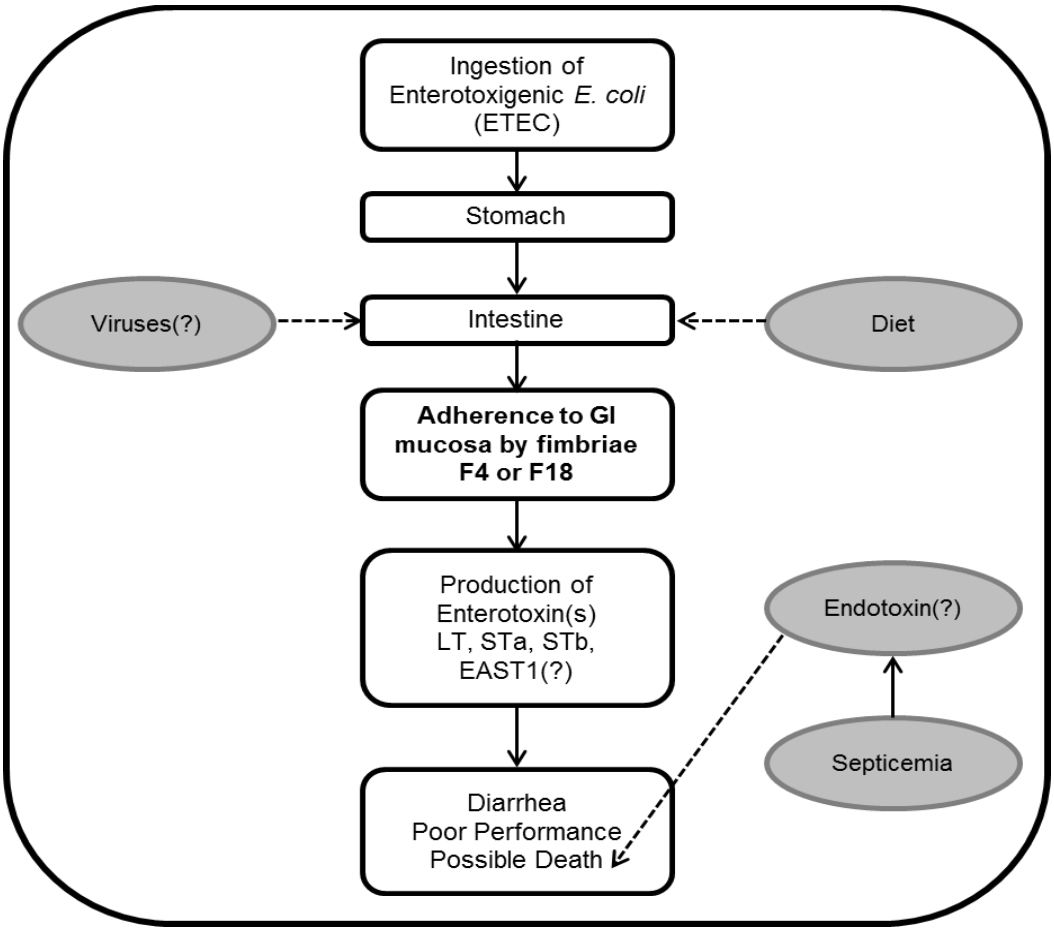
Within the first 14 days of weaning is normally when the PWECD appears and does not usually occur after 8 weeks of age (Francis, 2002; Frydendahl,

2002). The first step for the ETEC to cause PWD is ingestion by the pig. The bacteria have to be consumed in high enough numbers to grow and reproduce for gut colonization. The next step is attachment to the intestinal epithelium or in the mucus layer on the epithelium in the small intestine. Attachment will occur by the ETEC by the specialized fimbriae binding to special receptors on the enterocytes or mucus covering the enterocytes. After attachment in the mid-jejunum to ileum, the bacteria will grow and divide to more than 10^9 cfu/g (Fairbrother et al., 2005; Fairbrother and Gyles, 2012). Some of the ETEC containing the fimbriae F41, F6, and F5 (K99) will colonize the latter jejunum and ileum. However, the F4 fimbriae *E. coli* will colonize the entire length of the jejunum and ileum. Diarrhea is dependent upon the degree of colonization (Fairbrother et al., 2005). Diarrhea will lead to a decrease in growth and performance and in severe cases it can lead to death. Figure II.5 demonstrates a systematic approach to PWECD (Fairbrother et al., 2005).

There are many variables that can aid or cause PWECD. It has been observed that F4 usually causes the disease a couple of days after weaning. However, if the farm's rations contain high levels of plasma, zinc oxide, animal protein sources, and acidifying agents, diarrhea will peak at 3 weeks up to 6-8 weeks after weaning. In the F18 PWD, the receptors are not expressed until about 20 days of age and will normally cause diarrhea between 5-14 days after weaning.

If the temperature in a weaner room is low, the pigs are more likely to have a more brutal case of PWECD. The cold temperatures will decrease GI peristaltic movement, which, in turn, increases bacterial colonization (Fairbrother

Figure II.5 Pathogenesis of post-weaning *E. coli* diarrhea in nursery pigs



(Adapted from Fairbrother et al., 2005)

and Gyles, 2012). In a case study conducted in southern Ontario, it was determined when pigs with PWECD were compared to control (no diarrhea) pigs, several factors contributed to the diarrhea (Amezcua et al, 2002). Amezcua et al. (2002) concluded PWECD seemed to increase when a porcine respiratory and reproductive (PRRS) virus vaccination was administered and when the first diet

consumed by the weanling pigs was a pelleted diet. Another factor that increased PWECD was if the pigs had an unlimited or larger amount of feed space availability. It was suggested these factors aid in a reduced gut immunity, more nutrients available for the *E. coli* in the gastrointestinal tract, less nutrients absorbed by the pig, and over eating. In this study, it was determined that PWECD did not discriminate based on size or type of farm, as well as, commingling, weaning weight, and weaning age of pigs were not a factor (Amezcua et al., 2002).

Other factors may contribute to PWECD. A decrease in gut motility may increase the likelihood of the bacteria attaching and multiplying. Feeding a liquid diet at consistent intervals might reduce diarrhea. However, some have reported that restriction of feed could reduce the incidence of PWECD. Others have stated when the pigs consume less than 1000 g the first week diarrhea is increased. Loss of antibodies from the sow's milk escalates the chances of *E. coli* diarrhea (Pluske et al., 2002).

Rotavirus Diarrhea

Another agent aiding in post-weaning diarrhea is rotavirus. A rotavirus is a ubiquitous, non-enveloped, icosahedral, triple-layered, and double-stranded RNA pathogen that belongs to the family *Reoviridae* (Martella et al., 2007; Chang et al., 2012). First documentation of rotavirus in pigs was in 1975 (Chang et al., 2012). These viruses may be classified into groups A-G, which are named based on the binding to viral protein 6 (VP6; Martella et al., 2007; Chang et al.,

2012). The groups for porcine rotaviruses are groups A, B, C, and E (Chang et al., 2012). Group A rotavirus is one of the groups known to aid in diarrhea in weaning pigs (Martella et al., 2007). Group A rotavirus accounts for approximately 90% of diarrhea from rotavirus. It has been reported that the prevalence of the group A rotavirus is between 10-70% in diarrhea samples (Chang et al., 2012). Rotavirus group A has the capability to cross species and infect other animals and humans and is well characterized (Martella et al., 2007; Chang et al., 2012). This group of rotavirus can be detected in feces for approximately 7 days with a range of 1-14 days. Group A is most prevalent in pigs that are 3-5 weeks of age, but can be detected in pigs as early as 1 week of age (Chang et al., 2012).

The group C rotavirus is another virus that is prevalent in PWD. It has been reported that the prevalence of the antibody to this virus is present in 28-70% of pigs at 8 weeks of age (Martella et al., 2007). Group E rotaviruses have only been reported in the United Kingdom (Chang et al., 2012).

Lecce and King (1978) reported diarrhea in pigs 3 days after weaning, which lasted 5-10 days. In the fecal samples obtained, rotavirus was detected in 48% of the pigs with diarrhea with some of the numbers of rotavirus reaching ~10^9/mL in collected gut fluids. It is believed the stress of weaning and no supply of rotavirus antibodies from the sow's milk is what led to the diarrhea (Lecce and King, 1978).

The main route of transmission is via the fecal-oral route. After ingestion of the virus, it will replicate in the cytoplasm of villous epithelial cells located predominately in the jejunum and ileum. Once the rotavirus begins to replicate, the enterocyte will lyse. This lysing of the cell will promote villous atrophy and blunting. The degree of damage to the villi depends on the group of rotavirus, strain of virus, and age of the pig. It has been reported that younger pigs will have more damage. As well as, the groups A and C rotaviruses will tend to lead to more villi atrophy (Change et al., 2012).

The mechanism of diarrhea is due to malabsorption of nutrients due to damaged gastrointestinal cells. A few of the disruptions that occur due to the rotavirus are a decrease in disaccharide enzyme activity and a harmed glucose-sodium transporter. Due to the decrease in enzyme activity, there is a build-up of disaccharides in the lumen. This accumulation will cause a hyperosmolarity thus causing an osmotic diarrhea (Chang et al., 2012).

The clinical signs of a rotavirus infection, one without other pathogens, includes diarrhea that is white or yellow, and creamy to watery. The diarrhea is accompanied by mild dehydration. Death is inconsistent, but is usually less than 20%. However, when the rotavirus is present with another pathogen, like ETEC, the severity of diarrhea worsens. It is believed that the rotavirus allows for the ETEC to colonize better to the enterocytes in the gastrointestinal tract, thus eliciting a more intense diarrhea (Chang et al., 2012).

SUMMARY

In conclusion, there are many different aspects of weaning that affects post-weaning lag. A combination of all of the above mentioned areas plus others not mentioned decreases performance in pigs after weaning. Post-weaning lag is an extremely complex and complicated process to overcome. With that being stated, numerous research has and will continue to improve diets, the environment, etc. to decrease the effects of post-weaning lag.

METHODS OF REDUCING POST-WEANING LAG AND DIARRHEA:

Controlling and improving post-weaning lag in nursery pigs is very complex and complicated. There has been numerous research that have tried to improve growth performance after weaning (Ewtushik et al., 2000; Montagne et al., 2004; Nagy and Fekete, 2005; Domeneghini et al., 2006; Hermes et al., 2009; Bruins et al., 2011).

HIGH NUTRIENT DENSE DIET

One of the most common methods of improving post-weaning lag is the complexity of the diets fed to the pigs. These diets are considered to be high nutrient dense diets (HNDD). As the commercial industry has moved towards weaning pigs at earlier ages, the complexity of the diets have to be increased in order for the pigs to grow and meet their requirements. The younger the pig is when weaned the more complex the diet needs to be (Nelssen, 1986; Maxwell and Carter, 2001). However, these HNDD are very expensive. Therefore, adapting the pigs to a less complex, cheaper diet is a must in the commercial

industry. Nursery pigs are fed on a phase feeding program where complexity of diet decreases with each phase. Many farms use a four-phase feeding program, but it can fluctuate between 3 and 6 phases.

In a normal four-phase feeding program, the most complex diets are Phases 1 and 2 (DeRouchey et al., 2010). DeRouchey et al. (2010) stated there are several key feedstuffs that should be present in each diet phase. Phase 1 diet is the most complex diet. This phase has a high amino acid requirement that requires the use of multiple protein sources. The most commonly used protein sources for Phase 1 diets are blood cells, dried whey, fishmeal, soybean meal and further refined soy products, spray-dried animal plasma, spray-dried blood meal, and whey protein concentrate. These ingredients also aide in increasing feed intake. It is recommended that soybean meal be fed between the levels of 12-15% of the diet due to the allergic reaction the weanling pigs will have to certain proteins in the soybean meal. The blood products should be fed at less than 10% of the diet. The milk-based products should be at a level where the diet is 20-25% lactose.

Phase 2 diets are similar to Phase 1, but less complex. Some of the same protein sources are utilized, but at lower levels. The amount of soybean meal in the diet can be as high as 20% and the percent lactose in the diet is between 15 and 20%. The Phase 3 diet resembles more of a corn-soybean meal-based diet with a few specialty feed ingredients. This phase will have low levels of blood products, fishmeal, and poultry meal. It will also have less than 10% lactose. The soybean meal level will range between 26-28%. Phase 4 diet will be a corn-

soybean meal-based diet. The specialty ingredients are not needed during this phase and are cost prohibitive.

Growth promotants are added to HNDD in phases 1-3. Antibiotics, zinc, and copper are added at growth promoting levels. All can act like as an antimicrobial agent and help control with incidence of diarrhea. The antibiotic level is dependent on the active component in the antibiotic. A common zinc source is zinc oxide and a common copper source is copper sulfate. The pharmacological levels of zinc are 1,500 to 3,000 ppm and pharmacologic copper is added at 125-250 ppm (DeRouchey et al., 2010).

There are reasons for the complexity of nursery diets. The goal of a HNDD is to meet the requirements of the newly-weaned pig as best as it can by matching the sow's milk, meeting the enzymatic demands of the pig's GI tract, and decreasing nutritional and *E. coli* diarrhea so the pig can overcome post-weaning lag as quickly and effectively as possible.

HIGH NUTRIENT DENSE DIET SUPPLEMENTATION

The addition of supplements to nursery diets to aid or alleviate post-weaning lag has been researched by many. Some of the supplements help control diarrhea while others are added to help in digestion and to improve gut health.

Some supplements are added to reduce diarrhea. Bruins et al. (2011) reported a reduction in diarrhea when nursery pigs were fed 0.4% or 0.8% (w/w) of black tea extract, but had a negative impact on feed intake and growth

performance. Another way to reduce diarrhea is to reduce the number of pathogenic *E. coli*. When cooked white rice was used as the major carbohydrate source in a weanling pig diet, there was a reduction in *E. coli* and the feces was drier. This occurred in a diet that contained animal proteins and in another diet with just plant proteins. However, in this study if carboxymethylcellulose was added to the rice-base diet, the incidence of PWECD was increased (Montagne et al., 2004). In a review by Nagy and Fekete (2005), many different supplements were mentioned to help eliminate PWECD, such as the use of probiotics and competitive exclusions. Results were variable (Nagy and Fekete, 2005). In a review about swine enteric bacterial disease by Pluske et al. (2002), there were numerous supplementations reviewed. Some of supplements were the following: fiber, oligosaccharides, prebiotics, and resistant starch. Just like reported by Nagy and Fekete (2005), all supplements had variable results on reducing PWECD (Pluske et al., 2002).

Feed additives have also been researched to improve gastrointestinal health during weaning. Several researchers have studied the effects of amino acid supplementation on GI health. When weanling pigs were supplemented with 0.5% L-glutamine, the GI health was improved by increasing villi height and crypt depth, as well as, decreasing the villi:crypt ratio. Glutamine supplementation also decreased the number of mucosal apoptotic cells and increased the number of mucosal mitotic cells (Domeneghini et al., 2006). Ewtushik et al. (2000) studied the effects of amino acid and polyamine supplementation on GI health. The addition of either glutamate or arginine

increased the villus height in the duodenum and numerically increased the length, weight, and mucosa weight of the small intestine; however, there was no effect on growth performance (Ewtushik et al., 2000). Koopmans et al. (2006) reported similar results with improving gut health with another essential amino acid, tryptophan. Adding 5 g/kg of tryptophan to a conventional weanling diet increased the villi:crypt ratio, but did not affect performance (Koopmans et al., 2006).

When an antioxidant blend of vitamin C and E, tea polyphenols, lipoic acid, and microbial antioxidants was supplemented to newly-weaned pigs, a reduction in the gene expression of oxidative stress genes was observed. The blend reduced the expression of the genes *p53* and *PGC-1a*, thus helping barrier function by limiting oxidation (Zhu et al., 2012).

Hermes et al. (2009) reported an increase in performance in pigs fed a high fiber containing sugar beet pulp and wheat bran vs. a low fiber diet (7.15% vs. 5.3% TDN). An increase in the production of short chain fatty acids, a decrease in coliforms, an increase in the lactobacilli:enterobacteria ratio, or other changes occurring in the GI tract are plausible reasons for the improved growth (Hermes et al., 2009).

Zijlstra et al. (1994) reported an increase in performance when pigs were fed a milk replacer the first week after weaning. When compared to suckling pigs and pigs on a conventional diet, the pigs fed milk replacer were heavier and had

longer villi; therefore, the milk replacer aided in improving the GI health of the pigs (Zijlstra et al., 1994).

De Lange et al. (2010) reviewed various strategies to aide in development of gut health. A few supplements that were studied were organic and inorganic acids, feed enzymes, and essential oils. Most of these supplements mode of action for improving GI health was antimicrobial activity. As mentioned earlier with other supplements, results were variable on improving gut health of weanling pigs (de Lange et al., 2010).

NON-NUTRIENT WAYS TO REDUCE PWL

The environment, such as type of flooring, temperature, ventilation, and stocking density, of the nursery also aids in decreasing post-weaning lag in nursery pigs. Providing an environment that is clean and sanitized is crucial due to the poor immune status of the pigs. The flooring and walls need to be able to withstand high pressure spraying and frequent cleaning. The walls also need to be well insulated. When the newly weaned pigs enter the nursery facility, the floor temperature should be approximately 32°C (90°F). This temperature should be maintained for at least a week or possibly two weeks. After the first week of weaning, the room temperature can be decreased by 1.1-1.7°C (2-3°F) each week. Broad variations in temperature should be prevented because a health challenge could arise. Providing good air quality is important to help maintain a healthy growing environment for nursery pigs. Ventilation rates are dependent on the size of the pig and time of year. There is an increase in ventilation rates

with heavier pigs and hotter times of the year. The flooring in the nursery needs to be totally slotted, have low maintenance in daily cleaning, and must stay dry (Coffey et al., 1995).

Stocking density is important as well. The pig needs to have enough room to move around comfortably. Stocking density is dependent on size. An example is an 11.3 kg (25 lb) or less pig needs 2 sq. ft. of floor space. The feeder space should be that half of the pigs can eat at the feeder at one time and there should be 1 nipple waterer/10 pigs with a minimum of 2 waterers. The p.s.i. for the nipple waterer should be no greater than 20. All of these recommendations will help decrease some of the stress that comes with weaning. Obviously, following a good bio-safety protocol will help eliminate any extra health stress to the newly incoming pigs (Coffey et al., 1995).

SUMMARY

There are many different methods, whether it is supplementation and/or change in environment, to aide in decreasing the consequences of post-weaning lag. With that being said, the research mentioned above is not an all-exclusive list. It should also be dually noted that some of the methods of reducing PWL is not cost effective enough for producers to incorporate into their feeding strategies. Researchers are working everyday on ways to help and possibly eliminate the effects of post-weaning lag in nursery pigs.

ANTIBIOTIC USE IN SWINE DIETS:

As mentioned earlier, antibiotics are normal ingredient in nursery diets. Antibiotics are added to nursery diets to improve growth performance and decrease incidence of diarrhea. An antibiotic is a natural substance that is produced by bacteria, mold, or yeasts. It is considered an antimicrobial agent, as well as a feed additive (Cromwell, 2001; Jacela et al., 2009). A non-nutritive substance that is added to the diet to enhance growth performance and efficiency is considered a feed additive. A feed additive may be removed from a balanced diet without causing any nutritional deficiencies in the pig (Jacela et al., 2009). An antimicrobial agent is a compound that can be either bacteriostatic or bactericidal for the growth of microorganisms (Cromwell, 2001). As of 2009, the Food and Drug Administration (FDA) approval for antimicrobial use in the swine industry was twelve antibiotics and five chemotherapeutics (Table II.2). A chemotherapeutic is a chemically synthesized antimicrobial agent and grouped into the antibiotic category. Some of the antibiotics can be used in combination. A few examples are neomycin-oxytetracycline and chlortetracycline-sulfamethazine-penicillin (Cromwell, 2002).

Antibiotics are used in three basic levels in the animal industry. Therapeutic levels are treating animals for a disease and are used at high doses. Subtherapeutic levels are added at low levels to the diet to improve growth and performance (Cromwell, 2002). The subtherapeutic level is fed at 200 grams per ton or less for longer than a 2 week period (Holt, 2008). Lastly, there are

Table II.2 Antimicrobial agents approved for enhancing growth performance at subtherapeutic levels in swine feed

Antimicrobial agent	A, C, or Cmb*	Class	Inclusion level (g/ton)	Trade name
Apramycin	A	Aminoglycoside	150	Apralan
Arsanilic acid	C	Arsenical	10-30	Arsanilic acid
Bacitracin methylene disalicylate	A	Bacitracin	45-90	BMD
Bacitracin methylene disalicylate (BMD) + Chlortetracycline (CTC)	Cmb		BMD → 10-30; CTC → 400	
Bacitracin zinc	A	Bacitracin	10-50	Albac
Bambermycin	A	Bambermycin	2-4	Flavomycin
Carbadox	C	Quinozaline	10-25	Mecadox
Chlortetracycline	A	Tetracycline	10-50	Aureomycin
Lincomycin	A	Lincosamide	20	Lincomix
Neomycin	A	Aminoglycoside	10-50	
Oxytetracycline	A	Tetracyline	10-50	Terramycin
Penicillin	A	β-lactam	10-50	Penicillin
Roxarsone	C	Arsenical	22.7-34.1	3 Nitro
Tiamulin	A	Diterpene	10	Tiamutin
Tylosin	A	Macrolide	20-100 starter 20-40 grower 10-20 finisher	Tylan
Sulfamethazine	C	Sulfonamide	100	Sulfamethazine
Suflathiazole	C	Sulfonamide	100 g combined with CTC	Sulfa thizole
Virginiamycin	A	Streptogramin	5-10	Stafac

*A = antibiotic; C = chemotherapeutic; Cmb = combination of one or more antibiotic and/or chemotherapeutic

(Adapted from Cromwell, 2001; Gaskins et al., 2002; Hardy, 2002; Holt, 2008; Jacela et al., 2009)

antibiotics given to prevent disease at intermediate levels or prophylaxis levels (Cromwell, 2002).

For many years, antibiotics have been used in swine and other livestock industries. The FDA approved the use of antibiotics in animal feed in 1950 (Gersema and Helling, 1986). The use of antibiotics in the swine industry was adopted quickly, especially after Cunha and colleagues in 1950 demonstrated increased growth performance (Holt, 2008). Cromwell (2002) reported that in 1963 the animal industry was using about 1 million kilograms of antibiotics. By the mid-1980s, the usage had increased to more than 3 million kilograms. In 1988, 13 million kilograms of antibiotics were produced worldwide with 4.65 million kilograms being sold in the United States. Approximately half of those antibiotics were used for the livestock industry. In 2000, it was reported that 23 million kilograms of antibiotics were produced in the United States with thirty-six percent or 8 million kilograms of that being used for animals (Cromwell, 2002). In 2000, it was reported that 80% of all swine rations contained subtherapeutic antibiotics (Hogberg et al., 2009). As of 2001, roughly 80-90% of all nursery diets contained an antibiotic. In 2001, growing and finishing diets had antibiotics in roughly 70-80% and 50-60%, respectively. About 40 to 50% of all sow diets contained antibiotics (Cromwell, 2001).

MECHANISMS OF ANTIBIOTICS

Three main mechanisms are theorized to be the modes of action for antibiotics. Cromwell (2001) reported the theories are nutritional effects, metabolic effects, and a disease control effect.

Nutritional Effects

There is a substantial amount of backing for the nutritional effect mechanism. In the gastrointestinal tract, there are many different microbes. Some these microbes are beneficial to the host by producing nutrients that are needed by the host, like vitamins and amino acids. Then, the other set of microbes that are present compete with the animal for nutrients. It is believed that antibiotics shift the bacterial population to where more nutrients are available to the host. An increase in coliforms by feeding penicillin has been observed, as well as, an increase in yeast with animals fed streptomycin. Both of these microbial populations synthesize nutrients for the animal. When pigs were fed tetracycline, a decrease in lactobacilli was observed. Lactobacilli require amino acids that are in similar proportions as the pig. It is stated that this decrease in lactobacilli would help a pig that is consuming a diet that is slightly deficient in vitamins or amino acids (Cromwell, 2001). Cromwell (2001) also reported that virginiamycin helps spare protein and energy. It does so by decreasing the production of VFA, lactate, ammonia and amine. This is done by shifting the microbial population. These are just a few examples of how antibiotics support the nutritional effect mechanism (Cromwell, 2001).

Metabolic Effects

Cromwell (2001) reported another mode of action is antibiotics alter metabolic processes in the animal. Chlortetracycline has been shown to have an effect on nitrogen and water excretion. Tetracycline has been demonstrated to

inhibit fatty acid oxidation in the liver. This same antibiotic also decreases phosphorylation reactions in bacteria. Carbadox increased protein production in swine muscle cells (Cromwell, 2001). Cromwell (2001) stated that the metabolic effect is probably not likely due to some of the antibiotics are not absorbed by the enterocytes and the subtherapeutic levels are not high enough to elicit a growth promoting response.

Disease Control Effects

The last proposed mechanism is disease control. This is the most commonly accepted mode of action. It is believed that antibiotics decrease or "keep in check" the pathogenic microbes. This, in turn, allows for less energy to be spent towards controlling an infection and more towards muscle growth and production. Given this mechanism, antibiotics have a greater response in younger pigs than older pigs. The immune system of a younger pig is less established leaving it susceptible to a variety of diseases. A young pig does not have many immunoglobulins by the time they are weaned and weaning just adds further stress on the pig. Therefore, if a weaned pig is fed antibiotics and placed in a "dirty" nursery, it performs better than a pig that is not fed the antibiotics in the same "dirty" nursery. Antibiotics have a greater response when the environment is dirty when compared to a clean environment. It also responds greater to the slower growing pigs than the faster growing ones. Both of these responses, dirty environment and unthrifty pig, is due to the shifting of the microbial population via antibiotics (Cromwell, 2001). The mechanisms might change as more research is completed; however, the complete mechanism(s) of

antibiotics may never truly be understood due to the dynamic nature of the gastrointestinal tract.

PRODUCTION ENHANCEMENTS DUE TO ANTIBIOTICS

A review of 1,194 U.S. studies revealed the use of antimicrobials in nursery diets from 1950 to 1985. The review showed an increased growth rate of 16.4% and an improved feed performance of 6.9% (Cromwell, 2001; Maxwell and Carter, 2001). The use of subtherapeutic antibiotics or growth-promoting antibiotics is more effective in young pigs than older swine. Antibiotics, when feed intake is constant, improve growth performance. Protein and nitrogen metabolism are improved when pigs are fed antibiotics (Gaskins et al., 2002). The increase in performance is greater in the commercial industry than in a research (university) setting. Table II.3 shows the differences in performance when comparing a research farm to a commercial farm (Cromwell, 2001).

Table II.3 Comparing the effects of subtherapeutic antibiotics on growth performance in research settings vs. commercial settings

	% Improvement from Antibiotics	
Location	**Average Daily Gain**	**Feed:Gain**
Research	13.2-16.9	4.7-7.0
Commercial	25.5-28.4	10.0-14.5

(Adapted from Cromwell, 2001)

Besides increasing growth, antibiotics decrease mortality in young pigs. A review of 67 experiments performed revealed a 50% decrease in mortality in nursery pigs (Cromwell, 2001). Table II.4 shows the difference in mortality in

young pigs when fed antibiotics compared to control pigs, which were fed no antibiotics.

Table II.4 Comparing mortality in a commercial setting in young pigs fed a non-antibiotic diet (control) vs. antibiotic diet (antibiotic)

	% Mortality	
Health Status	**Control**	**Antibiotics**
Normal	4.3	2.0
High disease	15.6	3.1

(Adapted from Cromwell, 2001)

There is also a greater response to antibiotics in the diet when the environment is "dirty." When compared to pigs fed a control diet, pigs fed antibiotics had a 55%increase in gain in a "dirty" environment. If the same treatments are compared in a "clean" environment, the pigs fed antibiotics had a 28% improvement in gain than the pigs fed the control diet (Cromwell, 2001).

It should be noted that the previous studies were conducted at least over 20 year ago. It is believed that antibiotics in feed do not have the effect they use to because of changes in the swine industry. The swine industry has improved on its biosecurity, nutrition, and husbandry practices, as well as, having multi-site production facilities. A more recent study revealed that there is no improvement during the finishing phase, but there is still some improvement during the nursery phase when subtherapeutic antibiotics are fed (Table II.5). However, it should be dually noted that antibiotics in feed are important during a disease outbreak (Jacela et al., 2009).

Table II.5 More recent study on growth performance in a commercial setting in pigs fed a non-antibiotic diet (control) vs. antibiotic diet (antibiotic)

Production Phase	Performance Parameter	Control	Antibiotics	% Improvement
Nursery	ADG (lb)	0.96	1.01	5.2
	F:G	1.44	1.42	1.4
Grow-finish	ADG (lb)	1.72	1.72	0.0
	F:G	2.90	2.90	0.0

(Adapted from Jacela et al., 2009)

With all of the positive effects of antibiotics, its use at the subtherapeutic level is a concern. Subtherapeutic use of antibiotics has been a concern since 1969 when a report by the Swann Committee was given to the English Parliament, to now, where some countries, like European Union, Denmark and Sweden, have completely banned subtherapeutic antibiotics (Hogberg et al., 2009). Great Britain's response to the Swann Report was to have two categories of antibiotics, which were unprescribed feed additives and prescribed therapeutic antibiotics. The feed additive antibiotics were to only be used for the first three months (90 days) of life in all livestock (Gersema and Helling, 1986). In fact, Sweden was the first country to ban subtherapeutic use of antibiotics in diet in 1986. In 1997, European Union banned the use of Avoparcin as an in-feed antibiotic. Then, in 1998 Denmark banned the use of growth promoting antibiotics and the Netherlands prohibited Olaquindox (Hardy, 2002). The primary concern with subtherapeutic levels is antibiotic resistance. It has been estimated that in the United States alone antibiotic-resistant bacteria (ARB) have an economic yearly impact of $5-$24 billion (Ahmad et al., 2011).

SUMMARY

Antibiotics have been extremely instrumental in the swine industry in improving production and herd health. With that being said, there are those that argue the use of subtherapeutic antibiotics are detrimental to human health due to antibiotic-resistant bacteria. However, there are still those that continue to support the use of antibiotics in feed because is hard to establish antibiotic resistant patterns. As one knows, consumer perception is everything; therefore, the use of antibiotics in feed may eventually be banned in the United States. Consequently, there will need to be something to replace them.

ALTERNATIVES TO ANTIBIOTICS IN SWINE DIETS:

The use of antibiotics in livestock feed to improve overall health and performance have been used over 60 years (Gersema and Helling, 1986). However, with a growing concern of antibiotic-resistant bacteria, the subtherapeutic antibiotic usage in feeds is starting to decrease, especially in the swine industry. Therefore, there have been numerous feedstuffs studied to see if replacement or reduction of subtherapeutic antibiotics can occur. A two-part meta-analysis review by Pettigrew (2006) and Stein and Kil (2006) outline many of the feedstuffs used to reduce antibiotic usage. In Table II.6 there is a list of many of the feedstuffs and feeding regimens used to reduce the use of antibiotics in the swine industry. Not all of the list in Table II.6 will be discussed in this review of literature.

Pettigrew (2006) looked at several different alternatives. He stated that the addition of spray-dried plasma increases growth performance, on average, by 23%. Plasma protects the pig from *E. coli* and may contain "hunger" signals that increase feed intake. Another substitute studied is organic acids. The addition of organic acids increased growth by 6% after the first two weeks of weanling. The hypothesized mechanism is the acids decrease the pH of the stomach, thus changing the microbial population of the stomach. The pH and microbiota changes lead to improved nutrient digestion (Pettigrew, 2006).

Table II.6 A nonexclusive list of feedstuffs or feeding regimen used to reduce the use of antibiotics in swine feed

- Acids
- Alternative cereals
- Bacteriocins
- Bacteriophages
- Competitive inhibition
- Conventional egg products
- Copper
- Direct-fed microbials
  - *Bacillus*, *Lactobacillus*, *Streptococcus*
- Enzymes
  - Proteases, Lipases, Amylases
- Essential oils
- Fermented liquid feed
- Fructo-oligosaccarides
- Immune egg products
- Lactose
- Limit feeding
- Low protein diets
- Mannan oligiosaccarides
- Milk protein products
- Nucleotides
- Plant products
  - Saponins, Seaplants, Herbs, Spices
- Spray-dried plasma
- Yeast and yeast products
  - *Saccharomyces*
- Zinc

(Adapted from Turner et al., 2001; Pettigrew, 2006)

The addition of zinc, usually zinc oxide, is one of the most widely used feedstuffs in nursery diets. Zinc not only improves growth, but it protects the pig from enteric pathogens, like *E. coli* (Pettigrew, 2006).

The addition of live microbials or direct fed microbials (DFM) to the diet is another alternative. It is presumed the microbes colonize the gastrointestinal tract and out-compete potential pathogens. A DFM has to possess several characteristics to be functional. It has to be able to grow and establish itself in the intestinal tract, have a high growth rate, and several other characteristics. There are three main classes of DFM. These classes are: 1. *Bacillus*, 2. lactic acid bacteria (*Bifidobacterium*, *Enterococcus*, and *Lactobacillus*), and 3. yeast. The reported results on DFM are variable. Sometimes an improved growth performance is observed and other times it is not (Pettigrew, 2006).

Essential oils from herb and spice extracts have been used in nursery diets. The most common oils used are garlic, thymol, oregano, and carvacrol. The results with these essential oils are variable (Stein and Kil, 2006).

Wang et al., (2007) looked at the effects of feeding lactoferrin (LF) as a replacement for flavomycin-aureomycin (FA). The concentration of LF was 1 g/kg and FA was flavomycin (bambermycin) at 20 mg/kg and aureomycin (chlortetracycline) 110 mg/kg. When compared to pigs fed a control (no antibiotic) diet, the pigs fed either LF or FA had a higher final body weight, improved performance, decreased % diarrhea, and healthier GI tract due to microbial population and morphology (Wang et al., 2007). Lactoferrin has the potential to replace flavomycin-aureomycin in nursery diets in regards to the above mentioned parameters.

In a review by Close (2000), many additives were mentioned. Some of the additives have already been mentioned. Using enzymes, such as amylases, lipases, and proteases, improved digestion and absorption of nutrients thus improving growth performance. The addition of enzymes also decreases diarrhea (Close, 2000).

Turner et al. (2001) reviewed many antibiotic replacements. One category that was reviewed was plant products (echinecea, garlic, goldenseed, peppermint, saponins, seaplants, and rhubarb). The parameters researched were growth, feed intake, feed efficiency, gut function, and health/immune function. There was variability among the plant products in each category studied (Turner et al., 2001).

There are numerous amounts of research investigating subtherapeutic antibiotic replacements; however, more research is needed to find the appropriate levels of these alternatives and possible combinations that have comparable results to subtherapeutic antibiotics.

PLANT EXTRACTS AND POLYPHENOLS:

The most abundant antioxidants are polyphenols, which were referred to as “vegetable tannins” in early literature (D'Archivio et al., 2007; Ferrazzano et al., 2011). In human diets, polyphenols are the most abundant source of antioxidants. Polyphenols are in chocolate, beverages (i.e. coffee, tea, and wine), fruits and vegetables, olives, cereals, and dry legumes (D'Archivio et al., 2007). There are thousands of plant polyphenols. They all have a common

polyphenol structure, which are aromatic rings with several hydroxyl groups attached. Another commonality is the presence of at least one phenol ring (D'Archivio et al., 2007).

Polyphenols are classified into several different classes. The main classifications of polyphenols are phenolic alcohols, stilbenes, flavonoids, lignans, and phenolic acids. These groups are based on the number of phenol rings and the constituents that bind the rings together. Phenolic alcohols are present in wines, beer, and extra virgin olive oil. The two most common phenolic alcohols are tyrosol and hydroxytyrosol. Stilbenes are fairly low in the human diet. The most common stilbene is resveratrol. This compound is produced by a plant in response to a stressful condition or pathogenic infection. Resveratrol has been detected in over 70 plants. Some of these plants are grapes, peanuts, and berries. Flavonoids have the following common structure: two benzene rings which are connected by a linear 3-carbon chain, central 3-carbon chain, which may form a closed pyran ring with one of the benzene rings, and diphenyl propanes. The subdivisions of flavonoids are anthocyanidins, isoflavones, flavonols, flavanols, flavones, and flavanones. Currently, over 4,000 flavonoids have been identified and the list is growing. Oxidative dimerization of two phenylpropane units is how lignans are produced. The main source of lignan is rapeseed oil. Phenolic acids can be divided into two groups: derivatives of cinnamic acid (hydroxycinnamic acid) and derivatives of benzoic acid (hydroxybenzoic acid). The most abundant phenolic acid is caffeic acid. The

most abundant phenolic acid in cereal grains is ferulic acid (D'Archivio et al., 2007).

Polyphenols are a plant's chemical, secondary metabolite, defense mechanism. These antioxidant compounds are found in all parts of a vegetating plant, including the flower and fruit (Ferrazzano et al., 2011). Since polyphenols are antioxidants, they have the potential to protect the cell from oxidative damage (D'Archivio et al., 2007). An antioxidant is a compound that interferes with dissemination of a free radical or inhibits the formation of free radicals, thus delaying autoxidation. Prevention of oxidative damage is done by delaying autoxidation via inhibiting free radical formation. There are five different mechanisms on how this can occur: 1) reducing oxygen concentration, 2) preventing formation of peroxides, 3) breaking the chain of autoxidation, 4) chelating metal ions that can generate reactive species, and/or 5) scavenging peroxidation species (Brewer, 2011).

Polyphenols have the potential to prevent or treat arthrosclerosis, diabetes mellitus, cancer, cardiovascular disease, osteoporosis, neurodegenerative disease, and many more diseases (D'Archivio et al., 2007; Cherniack, 2011; Ferrazzano et al., 2011). Some of the ways polyphenols prevent diseases are by stimulating the production of cytokines via macrophages and monocytes, preventing bacterial replication, tumor cell apoptosis, and neutrophil stimulation. The antimicrobial actions of these compounds are intriguing because of their capability to detoxify bacterial toxins, thus being used as a new drug against antibiotic-resistant bacteria (Ferrazzano et al., 2011).

Many spices and herbs, like turmeric, contain antioxidant polyphenolic compounds that can be isolated and used in food to inhibit oxidation. The compounds isolated/concentrated can be essential oils, extracts, or resins. An essential oil is removed by solvent or carbon dioxide extraction, mechanical extraction from the plant, or steam distillation. These compounds are highly volatile compounds. The extracted oils are complex blends that contain many functional classes. An extract is a soluble portion that can be removed by solubilizing in alcohol, aqueous, lipid, solvent, or supercritical carbon dioxide phase. A resin is a shapeless, high molecular weight, nonvolatile semisolid or solid that will flow when heat or stress is applied to the plant. These compounds are not soluble in water, but are in many organic solvents. Resins are characteristically pale yellow to dark brown, slightly fragrant or odorless, tasteless, and transparent or translucent (Brewer, 2011). A spice that fits into this group of polyphenols is turmeric.

TURMERIC CHARACTERISTICS:

The use of complementary and alternative medicine (CAM) is rising in humans. Reddy et al., (2013) estimated that 50% of the human population uses alternative medicine. A 300% increase in the use of herbal medicine was observed from 1990 to 1997 (Reddy et al., 2013). With this rise in the human population and the greater demand of organic products in livestock production, herbal use in the livestock industry is beginning to occur. Turmeric is a very popular CAM product that is and has been used for decades.

Turmeric, *Curcuma longa* Linn, is a very prominent herbaceous spice used in Southeast Asian countries dishes, such as India and China (Tayyem et al., 2006; Bengmark et al., 2009) and is part of the ginger family or Zingiberaceae (Brewer, 2011). Turmeric has been used in these countries since 700 AD for medicinal purposes (Lantz et al., 2005; Tayyem et al., 2006; Rajasekaran, 2011). Marco Polo even mentioned turmeric in his travels in the late 1200's to India and China (Esatbeyoglu et al., 2012). Currently, turmeric is approved as a food additive, where it is used as a preservative and coloring agent in many foods (Tayyem et al., 2006; Bengmark et al., 2009). Turmeric has a bitter, tart taste and a spicy, aromatic aroma (Esatbeyoglu et al., 2012). Research has demonstrated no adverse effects of consuming 8,000 mg of turmeric a day for three months (Reddy et al., 2013).

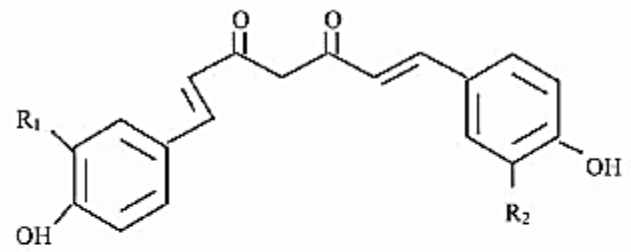
Turmeric is a Tropical perennial rhizome (Zhang et al., 2010; Brewer, 2011; Esatbeyoglu et al., 2012). Due to its requirements of needing lots of water and a hot, humid climate, turmeric is grown in the China, Indian, and South East Asia. India is the major consumer, exporter, and producer (Esatbeyoglu et al., 2012). The rhizomes are horizontal underground stems, which grow roots and shoots (Brewer, 2011). The rhizomes contain non-volatile and volatile components. The major volatile components are turmerone, zingiberen, curlone, and *ar*-Turmerone (Zhang et al., 2010).

Curcumin, demethoxycurcumin (DMC), and bisdemethoxycurcumin (BDMC) are the major non-volatile, fat soluble, polyphenolic compounds or curcuminoids and are the major components in turmeric (Zhang et al., 2010;

Brewer, 2011). Figure II.6 shows the chemical composition of the three curcuminoids. These natural analogues have many different properties that include antioxidant, anti-inflammatory, anticarcinogenic, and antimicrobial (Anand et al., 2008; Rajasekaran, 2011).

Turmeric oil is compared to vitamin E and butylated hydroxytoluene (BHT) in terms of free radical scavenging capabilities. The compounds responsible for the antioxidant activity are curlone, α-terpineol, and α- and β-turmerone. When turmeric oil is heated, the antioxidant activity increases (Brewer, 2011). The traditional Chinese medicine Xiaoyao-san uses turmeric as a stress manager and

Figure II.6 Chemical structures of the three curcuminoids present in turmeric



	R_1	R_2
Curcumin	$-OCH_3$	$-OCH_3$
Demethoxy-curcumin	$-OCH_3$	-H
Bis-demethoxy-curcumin	-H	-H

(Bengmark et al., 2009)

to help treat depression disorders. Turmeric is a powerful inhibitor of potassium channels (Al-Suhaimi et al., 2011). It has the ability to repress induced cataracts in mice. Turmeric also has the capability to decrease blood glucose levels in type 2 diabetic mice (Gupta et al., 2013). There are many diseases and medical

problems turmeric has shown to help or inhibit. The above mentioned data is just a few examples of the capabilities of turmeric.

CURCUMIN CHARACTERISTICS:

Giving turmeric its characteristic yellow color and the most active component is curcumin or 1,7-bis (4-hydroxy-3-methoxyphenol)-1,6-heptadiene-3,5-dione (Lantz et al., 2005; Bengmark et al., 2009). Curcumin was discovered over two centuries ago by Vogel and Pelletier. They reported a "yellow coloring-matter" and thus named it curcumin. Vogel Jr. isolated a pure sample of curcumin in 1842, but did not report the formula. In 1910, Lampe and Milobedzka identified the structure of diferuloylmethane or curcumin (Gupta et al., 2012). It is characterized as an unsaturated diketone. Curcumin displays keto-enol tautomerism (Brewer, 2011). Several different analogs of curcumin are found in other plants. These analogs include: cassumunin, diarylheptanoids, 6-paradol, yakuchinones, 6-gingerol, 8-gingerol, galanals, isoeugenol, and dibenzoylmethane (Al-Suhaimi et al., 2011).

The concentration of the curcumin in turmeric is extremely variable, which is thought to be dependent on soil acidity and available nutrients to the plant. Research has shown that the highest concentrations of curcumin are found in pure turmeric powder (Tayyem et al., 2006). It has been stated that the average curcumin in turmeric is between 4-5% (Bengmark et al., 2009). Most commercially available curcumin is not 100% curcumin. It is 77% curcumin, 17% DMC, and 3% BDMC (Anand et al., 2008).

Curcumin has shown to decrease tumor necrosis factor-alpha (TNF-α), interferon-γ (IFN-γ), and cyclooxygenase (COX), suppress NF-κB activation, and to impede inducible nitric oxide synthase (iNOS) and vascular endothelial growth factor (VEGF), C-reactive protein (CRP), and prostaglandin E2 (Rajasekaran, 2011). It is proposed the lower incidence of colorectal cancer in Asians is due to the consumption of curcumin (Tayyem et al., 2006). Al-Suhaimi et al., (2011) reported curcumin has been demonstrated to protect mice Leydig cells from chronic alcohol consumption. Curcumin has also been shown to decrease depression in depression-induced mice (Al-Suhaimi et al., 2011). Curcumin is an antioxidant by donating hydrogens from its phenolic groups; thus making it extremely successful in free radial neutralization. It has more antioxidant activity than BHT and resveratrol (Brewer, 2011). Besides having antimicrobial and antioxidant effects, curcumin has been shown to be a chemopreventative and be hypolipidemic (Tayyem et al., 2006). In humans, curcumin has demonstrated activities against Crohn's disease, cancer, ulcerative colitis, gastric ulcer, peptic ulcer, atherosclerosis, irritable bowel syndrome, and gastric inflammation, just to name a few (Gupta et al., 2013). This is not an all-inclusive list of curcumin's capabilities.

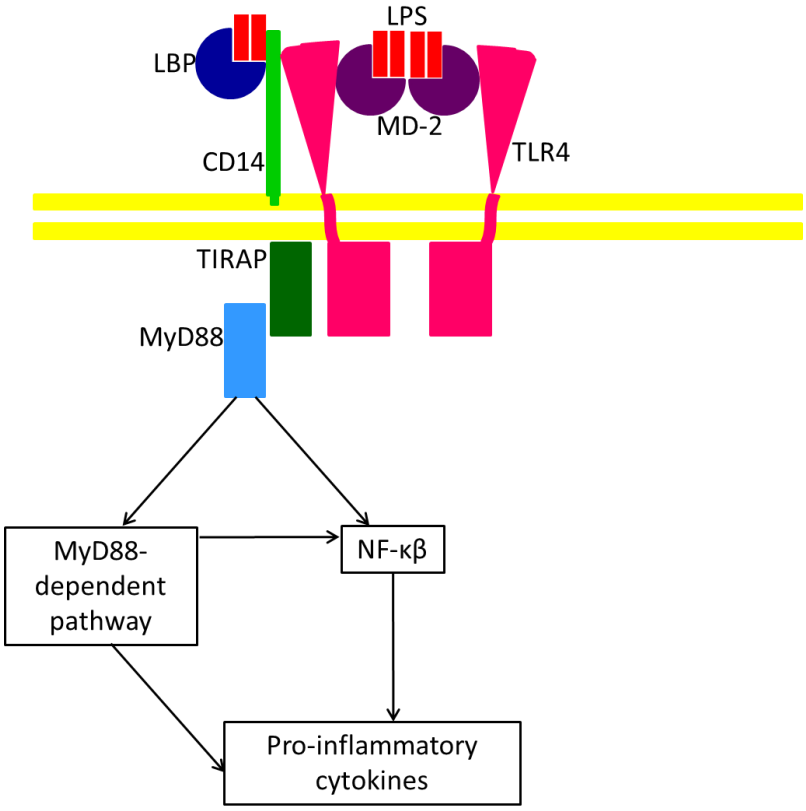
LIPOPOLYSACCHARIDE CHALLENGE AND SWINE:

As mentioned earlier, curcumin and turmeric have many different properties. Two of those properties are decreasing inflammation and antimicrobial. An excellent model to study these properties is a lipopolysaccharide challenge.

Lipopolysaccharide, a cell wall component, affects the animal immunologically as live bacteria would (Mandali et al., 2002), thus initiating an innate immune reponse. The Toll-like receptors (TLRs) activation occurs via pathogen-associated molecular patterns (PAMPs), which are expressed by viruses, bacteria, and fungi. Thus, TLRs initiate the expression of the pro-inflammatory cytokines. Several PAMPs stimulate TLR4. One of these molecules is Gram-negative bacterial LPS. Of the three components of LPS (lipid A, O side chain, and core oligosaccharide), the lipid A is the primary PAMP or activator. The stimulation of mammalian cells via LPS occurs using several different proteins. The soluble shuttling protein, LPS binding protein (LBP), binds LPS and carries it to cluster of differentiation 14 (CD14). Lipopolysaccharide binds to CD14, which helps move the LPS to the TLR4/MD-2 (myeloid differentiation protein 2) complex. This binding initiates a downstream signaling that leads to the activation of the pro-inflammatory cytokines, such as IL-6 and TNF-α, via NF-κB pathway (Lu et al., 2008; Bryant et al., 2010). Figure II.7 gives a visual illustration of the process. These pro-inflammatory cytokines act on various pathways and are produced by macrophages (van Heugten et al., 1994).

One of these pathways is the metabolism of arachidonic acid. The metabolites of this process include lipooxygenase (LOX) products or leukotrienes and cyclooxygenase (COX) products, such as prostaglandins (Lantz et al., 2005). One of the products of the COX process is prostaglandin E2 (PGE2). This blood brain barrier crosser, PGE2, binds to its receptors in the brain, which will activate

Figure II.7 Signaling cascade from lipopolysaccharide (LPS) to the activation of pro-inflammatory cytokines



(Adapted from Lu et al., 2008)

the thermal neurons in the anterior hypothalamus. The activation will cause the body to have a higher body temperature, thus leading to a fever (Ogoina, 2011). An increase or peak in rectal temperatures in swine indicates that an immune response has occurred (Van Gucht et al., 2004).

It has been demonstrated that during an *E. coli* lipopolysaccharide (LPS) challenge that the pro-inflammatory cytokines interleukin-6 (IL-6), interleukin-1β (IL-1β), and TNF-α are increased in a time-dependent manner. The peak hours for IL-6, IL-1β, and TNF-α were 2.5 h, 3 h and, 1 h post-LPS, respectively.

Epinephrine, cortical, and norepinephrine were also increased in a time-dependent manner. These stress-related hormones peaked 30 minutes after injection (Williams et al., 2009). Williams et al. (2009) also showed that there is a drastic decrease in WBC counts during a LPS challenge. At hour 5.5 post-inoculation, total WBC had decreased by 55% when compared to hour 0. There was a decrease in monocytes, lymphocytes, neutrophils, basophils, and eosinophils by 77%, 87%, 13%, 75%, and 94%, respectively (Williams et al., 2009). Webel et al. (1997) reported after 2 hours of an intraperitoneal injection of 5 µL/kg of body weight of LPS *E. coli* K-235, plasma TNF-α was elevated 10-fold and IL-6 was elevated 200-fold by hour 4 of the challenge. There was also an increase in cortisol levels, plasma urea nitrogen (PUN), triglycerides, and a decrease in glucose. All changes occurred in a time-dependent manner (Webel et al., 1997). A LPS challenge has shown to decrease growth performance (van Heugten et al., 1994).

It has been reported that an LPS challenge negatively affects the gastrointestinal tract by causing villous atrophy and other GI problems, which leads to a decrease in nutrient absorption (Mandali et al., 2002). Lipopolysaccharide challenge also leads to catabolism of the muscle tissue and a decrease in the expression of IGF-1 (Weber and Kerr, 2008). Weber and Kerr (2008) reported 4 hours after an intramuscular infection of *E. coli* LPS, control pigs had an increase in IL-6, TNF-α, nonesterified fatty acids (NEFA), and cortisol and a decrease in IGF-1, blood urea nitrogen, glucose and triglycerides.

Another disease that LPS can induce is a Gram negative septic shock. There is an over production of the pro-inflammatory cytokines, abnormal coagulation, and proteolytic cascades. This leads to hypotension and multiple organ failure (Beumer et al., 2003) and possible death. Administration of lipopolysaccharide is a well-documented model of disease stress in swine.

TURMERIC/CURCUMIN AND LIPOPOLYSACCHARIDE CHALLENGE:

Curcumin has been shown in previous studies to attenuate a LPS response by inhibiting or decreasing pro-inflammatory cytokines (Sompamit et al., 2009). One reason for the lower concentrations could be the curcumin in the dietary turmeric inhibited the binding of LPS. It has been suggested that curcumin has the ability to bind to the MD-2. The MD-2 protein is involved in the TLR4/MD-2 complex that binds to CD14. And CD14 binds LBP, which binds LPS (Gradisar et al., 2007). However, it might not be curcumin alone that helps inhibit the immune response. Lantz et al. (2005) demonstrated that curcumin and an organic extract of turmeric were capable of inhibiting the TNF-α and PGE2 pathways. The other curcuminoids, DMC and BDMC, could have an effect. Zhang et al. (2008) reported the potency of curcuminoids for decreasing TNF-α and nitric oxide were DMC > BDMC > curcumin. This was in LPS-infected rat microglia. One mechanism is the ability for curcumin to inhibit NF-κB binding. Zhong et al. (2011) reported that curcumin inhibited the binding of NF-κB to DNA in mice HK-2 (renal) cells infected with LPS. One thing is understood and that is curcumin is a pleiotropic molecule (Gupta et al., 2012).

TURMERIC/CURCUMIN AND SWINE:

There has been little research published with swine and turmeric or curcumin. Most of the studies have dealt with enhancing growth performance. Yan et al., (2011) demonstrated that pigs fed an herbal extract mixture of black pepper, curcuma, ginger, buckwheat, and thyme had comparable ADG and ADFI to pigs fed a subtherapeutic antibiotic (apramycin) diet when it was fed at 250 mg/kg and 500 mg/kg. The herbal mixture contained approximately one-third curcuma. Both treatments of herbal fed pigs also had higher white and red blood cell counts and % lymphocytes than the antibiotic fed pigs after 6 weeks (Yan et al., 2011).

Maneewan et al. (2012) reported an increase in nutrient digestibility of crude protein, crude fat, crude fiber, ash, and biological value of protein in pigs fed increasing levels of turmeric. The levels of turmeric were 0%, 0.05%, 0.10%, and 0.20%. The higher levels of turmeric (0.10% and 0.20%) had the highest levels of digested nutrients. However, there were no differences observed growth performance for pigs fed turmeric when compared to a control with no antibiotics (Maneewan et al., 2012).

However, Ilsely et al. (2005) reported no effect on growth performance or immune status in nursery pigs fed 200 mg/kg of curcumin. When pigs were fed 1551 mg/kg of BW/d of turmeric oleoresin, an adverse effect was noted on weight gain and feed conversion rate. It was also observed in the same study that as turmeric intake increased, thyroid and liver weights increased (Bille et al.,

1985). After a porcine reproductive and respiratory syndrome (PRRS) virus infection, nursery pigs fed 10 mg/kg of turmeric oleoresin had better G:F than the control pigs. In addition, turmeric increased ADG at d 7-14 PI and d 0-14 PI (Liu et al., 2013a). Even with little data concerning growth performance in swine and turmeric, a wide variation in results exists.

More recently, Wei et al. (2010) reported feeding 8 mg/kg of curcumin to pigs helped alleviate traveling stress. The pigs fed curcumin had a decrease in hippocampal nitric oxide production, serum cortisol concentration, and an increase in mRNA expression of brain-derived neurotrophic factor after traveling on the road for 2 hours. There was also a reduction observed in the following enzymes: total nitric oxide synthase (NOS), constitutive NOS (cNOS), and inducible NOS (iNOS), as well as, a decrease in the expression of cNOS in the pigs administered curcumin.

Turmeric as a healing agent in swine has also been studied. One disease that has been researched is scabies. Swine scabies is a skin disease caused by *Socroptic scabiei* var *suis* (Dwivedi and Sharma, 1985). Dwivedi and Sharma (1985) made a treatment that was 50 mL of sesame oil with the following plants added: 8 mL each of lemon and onion extract, 17 mL of garlic extract, 1 g of camphor, and 8 g each of Gunja seed and turmeric powder. The treatment was applied topically daily for 5 days at 20 mL/day to the infected pigs. By day 3 of treatment, the drug was healing the scabies. It was concluded by 30 days post treatment that the only effect observed was that 2 of the 7 treated animals had a wrinkling and slight thickening of the skin. The 4 control pigs after 30 days post-

treatment still had scabies. It was suggested that the turmeric's role in the drug was acting as an antimicrobial and possibly causing hair follicle stimulation (Dwivedi and Sharma, 1985).

Dwivedi and Sharma (1986) performed another scabies study using a very similar plant extract concoction. The scabies treatment was 54 mL of Karanj oil with 18 mL of garlic extract, 9 mL of lemon extract, 9 mL of onion extract, 1 g of camphor, and 9 g of turmeric powder. Again, infected pigs had 20 mL of the drug applied topically daily for 5 days. The results were similar to the previous study. The healing process was observed by day 3. All of the treated pigs showed no clinical signs of scabies for 90 days (maximum days of testing). The thickening and wrinkling of the skin did progressively decrease over the 90 day period. However, the 4 control pigs with scabies continued to worsen after 90-day post-treatment (Dwivedi and Sharma, 1986).

SUMMARY:

Post-weaning lag in nursery pigs is still a problem in the swine industry. It causes detrimental effects in the nursery pig. The abrupt change in diet, sow milk to dry feed, produces a decrease in gastrointestinal enzyme activity, intestinal damage to the villi, low voluntary intake, and many more negative impacts on the newly-weaned pig. When subtherapeutic antibiotics are supplemented to a high nutrient dense diet, post-weaning lag is reduced. Subtherapeutic antibiotics improve growth performance, and decrease mortality and diarrhea in nursery pigs. However, there is a growing concern of antibiotic

use in the livestock industry because of the increase in antibiotic-resistant bacteria. However, with that being said, it is hard for the swine industry to just abandon the use of antibiotics because of all of the beneficial effects they provide. Numerous research has been conducted looking at replacing antibiotics in feed, but the results are variable. Thus, other means should be researched due to consumer concern. A possible replacement for subtherapeutic antibiotics is turmeric, or the most active component in turmeric, curcumin. Turmeric and curcumin have many properties, including anti-inflammatory and antimicrobial. Therefore, the addition of turmeric or curcumin to nursery diets has the potential to perform as well as, if not better than, subtherapeutic antibiotics.

CHAPTER III

EXPERIMENT I

EFFECTS OF INCREASING LEVELS OF TURMERIC POWDER ON GROWTH PERFORMANCE AND IMMUNE RESPONSE TO AN *E. COLI* LIPOPOLYSACCHARIDE CHALLENGE OF NURSERY BARROWS

M. R. Bible[1], S. D. Carter[1], H. J. Kim[1], T. M. Walraven[1], C. Houchen[2,5], S. Anant[3,4], and R. Ramanujum[4,5]

[1]Oklahoma State University, Stillwater, OK, [2]Oklahoma University Health Sciences, Oklahoma City, OK, [3]Kansas University Medical Center, Kansas City, KS, [4]Swaasth, Inc., Oklahoma City, OK, and [5]ADNA, Inc., Dublin, OH.

ABSTRACT

Turmeric is a common dietary spice used in India and Southeast Asia that contains the active ingredient curcumin, a potent polyphenolic phytochemical. Curcumin and curcuminoids in turmeric are known to have anti-inflammatory and antimicrobial activities. Therefore, thirty-two crossbred (D x (L x Y)) barrows (20 d of age) were weaned and used to determine the effects of dietary turmeric on performance and immune response. Pigs were blocked by BW and stratified by ancestry, and allotted randomly to four dietary treatments in a randomized complete block design. Pigs were housed in individual crates in an environmentally-controlled building (8 pigs/trt). During a 3-d adjustment period to the crates, barrows consumed a standard, phase 1, nursery diet. After this period, the experimental diets were fed for 21 d. A corn-soybean meal-based diet (1.44% SID Lys) containing no antibiotics or zinc oxide served as the control. The experimental diets contained increasing levels of turmeric at 2, 4, and 8 g/kg of diet, respectively. ADG, ADFI, and G:F were calculated weekly. Turmeric and curcumin consumption per day (linear, $P < 0.0001$) increased with the addition of turmeric in the diet. Turmeric increased ($P = 0.02$; quad) final BW, ADG, ADFI, and G:F ($P = 0.03$; linear). On d 20, a lipopolysaccharide (LPS) challenge was performed. Pigs were intraperitoneally administered saline-based *E. coli* O111:B4 LPS (25 µg/kg of BW). Rectal temperature (RT) was measured and blood was collected for the analysis of tumor necrosis factor (TNF-α), C-reactive protein (CRP), blood urea nitrogen (BUN), glucose, total protein, and triglycerides at 0 h, and 3, 6, 12, and 24 h post-injection. Turmeric numerically decreased

rectal temperature and TNF-α at h 3 PI. There were no differences (P > 0.10) for BUN, CRP, or glucose. However, at h 0 triglycerides were increased (P = 0.04; quad) as turmeric increased. A tendency was observed for turmeric to increase (P = 0.08; quad) total protein at h 0, and at h 24 turmeric decreased (P = 0.04; cubic) total protein. In conclusion, dietary turmeric increased performance and numerically lowered the inflammatory cytokine, TNF-α, during an *E. coli* LPS challenge in weanling pigs.

INTRODUCTION

Turmeric, *Curcuma longa* Linn, is a very prominent herbaceous spice used in Southeast Asian countries, such as India and China (Tayyem et al., 2006; Bengmark et al. 2009). Turmeric has been used in these countries since 700 AD for medicinal purposes (Lantz et al., 2005; Tayyem et al., 2006; Rajasekaran, 2011). Currently, turmeric is approved as a food additive, where it is used as a preservative and coloring agent in many foods (Tayyem et al., 2006; Bengmark et al., 2009).

There are three major components or curcuminoids in turmeric, which are curcumin, demethoxycurcumin, and bisdemethoxycurmin (Zhang et al., 2010). These natural analogues have properties that include antioxidant, anti-inflammatory, anticarcinogenic, and antimicrobial (Anand et al., 2008; Rajasekaran, 2011). Giving turmeric its characteristic yellow color and the most active component is curcumin (Lantz et al., 2005; Bengmark et al., 2009). The concentration of the curcumin in turmeric is extremely variable, which is thought

to be dependent on soil acidity and available nutrients to the plant (Tayyem et al., 2006). Research has shown that the highest concentrations of curcumin are found in pure turmeric powder (Tayyem et al., 2006). Curcumin has been shown to decrease tumor necrosis factor-alpha (TNF-α), interferon-γ (IFN-γ), and cyclooxygenase (COX), and suppress NF-κB activation (Rajasekaran, 2011). However, turmeric has a strong odor and smell, and a bitter taste, which could decrease feed intake of nursery pigs (Esatbeyoglu et al., 2012).

Therefore, the first objective of this study was to determine the effects of increasing levels of turmeric powder on feed intake and growth performance. Secondly, it was to determine the effects of the immune response during an *Escherichia coli* lipopolysaccharide challenge after feeding turmeric for 21 days.

MATERIALS AND METHODS

Turmeric Analysis

The turmeric powder was analyzed for curcumin, bisdemethoxycurcumin, and demethoxycurcumin concentrations. The analysis was performed by GAAS, Corporation (Tucson, AZ) using an HPLC. Briefly, samples were extracted with an 80:20 solvent mixture of methanol:water. Approximately 2 mL of the supernatant was transferred to an amber HPLC vial and injected into the column. The column type and size was a Kinetex C18, 2.6 µ, 150 x 4.6mm column. All standards used were greater than 91% pure.

Animal Care and Feeding

A total of thirty-two crossbred (Duroc x (Landrace x Yorkshire)) barrows (7.47 kg) were weaned at 20 days of age and allotted randomly to one of four dietary treatments with 8 replicates per treatment. The barrows were handled and cared for following the guidelines established by the Oklahoma State University Institutional Animal Care and Use Committee. The pigs were blocked randomly by BW, stratified by ancestry, and housed in a temperature controlled environment in individual stainless steel metabolic crates. Each pig had a 3-d adjustment period prior to starting the dietary treatment. During this period, barrows consumed a standard, phase 1 nursery diet. The four dietary treatments were: control (containing no antibiotics or zinc), 2, 4, or 8 g of turmeric/kg of feed (Swaasth, Inc., Oklahoma City, OK), respectively (Table III.1). Turmeric (TUM) levels were chosen to be below, above, and equal to a human consuming 12 g of turmeric/68 kg of BW, which is 176 mg/kg of BW (Esatbeyoglu et al., 2012). All diets exceeded the requirements listed in the Nutrient Requirements for Swine (NRC, 1998).

After the adjustment period, baseline measurements (d 0) were recorded and collected. This included BW, blood, and feed intake. The pigs were allowed to consume feed and water *ad libitum*. Water was provided via water nipples and each crate had a single-hole stainless steel feeder. The grams of feed consumed were recorded for each barrow. Any wasted feed was collected, dried, and weighed. Consumed and wasted feed were used to calculate ADFI

and G:F. Body weights were measured on d 0, 7, 14, and 21, and used to calculate ADG and G:F.

Blood Collection

Blood samples from each barrow were collected at d 0, 7, 14, and 21. Blood was drawn from the anterior vena cava (jugular) in the supine position using a 20 gauge 3.8 cm vacutainer needle with a 10 mL sterile serum tube (BD, Franklin Lakes, NJ). The d 0 sampling period was used as the baseline. The blood samples were placed on ice after collection and stored at 2-5°C overnight. The samples were centrifuged for 20 minutes at 2,000 x *g* to separate the serum. The serum was collected using a plastic transfer pipet and dispensed into appropriately labeled microcentrifuge tubes. The tubes were stored at -20°C until further analyses.

Escherichia Coli Lipopolysaccharide Challenge

On d 20 of the experiment, each pig was subjected to a lipopolysaccharide (LPS) challenge. To study the immune response, the *Escherichia coli* O111:B4 LPS (Sigma-Aldrich, Co., St. Louis, MO) was suspended in 9 g/L of sterile saline for a final concentration of 25 µg/kg of body weight (Mandali et al., 2000; Mandali et al., 2002; Smith, 2006; Bible, 2009). Feed was removed from the feeders prior to LPS injection. Before the LPS challenge, rectal temperature and body weight were recorded, and blood samples were drawn from each pig (h 0). Pigs were injected in the lower abdomen in the intraperitoneal cavity with the weight-dependent LPS suspension. Besides the h 0 readings, rectal temperature and

body weight were recorded and blood was drawn at 3, 6, 12, and 24 h post-infection.

Changes in rectal temperature and % BW of h 0 were calculated using h 0. Barrows were fed 0.907 kg of their assigned dietary treatment between 12 and 24 h post-injection. The wasted feed was dried and weighed to calculate FI.

Blood Serum Analysis

Serum samples from d 0, h 0 pre-LPS injection, and 3, 6, 12, and 24 h post-LPS injection were analyzed for TNF-α, CRP, BUN, glucose, total protein, and triglycerides. To test the concentrations of TNF-α, an enzyme-linked immunosorbent assay (ELISA) kit was used (R&D Systems, Inc., Minneapolis, MN). Serum samples were analyzed following the manufacturer's instructions. The 3 h post-injection samples were diluted 10-fold. The inter-assay CV was 2.7% and the intra-assay CV was 6.9%. Glucose, BUN, total protein, triglycerides, and CRP were analyzed using a Biolis24i Chemistry Analyzer (Carolina Liquid Chemistries Corp., Winston-Salem, NC). The intra-assay CVs for BUN, glucose, total protein, triglycerides, and CRP were 6.2, 6.5, 2.3, 3.1, and 7.5%, respectively. Manufacturer's directions were followed. Calibrators, controls, and BUN, glucose, total protein, triglycerides, and CRP HS wide range reagents were purchased from VWR (Radnor, PA).

Statistical Analysis

All data were analyzed using a randomized complete block design (SAS Institute, version 9.2). Due to unequally spaced levels of turmeric, coefficients

were derived using SAS Proc IML. Growth performance, LPS growth performance, LPS rectal temperature, and LPS blood chemistry data were analyzed using a GLM procedure. The LPS data was sorted by hour before analysis. Orthogonal polynomial contrasts (linear, quadratic, and cubic trends) were used to analyze the effects of increasing levels of turmeric powder, as well as, a non-orthogonal contrast of no turmeric vs. turmeric. Changes in LPS rectal temperature and blood chemistry data were analyzed using a repeated measures analysis of variance. The first-order autoregressive covariance structure was implemented. Slice effect was used to test for any differences between treatments at different time points. Pig served as the experimental unit. The treatment means are presented as least squares means. Differences were considered significant at the $P < 0.05$ level and a trend at $0.05 < P > 0.10$.

RESULTS

Curcuminoid Concentrations

The concentrations of curcumin, demethoxycurcumin, and bisdemethoxycurcumin for the turmeric powder were 2.36%, 1.04%, and 0.69%, respectively (Table III.2).

Growth Performance

All growth performance data are presented in Table III.3. There were no differences ($P > 0.10$) in initial (d 0) BW of the barrows with a mean BW of 7.47 kg. At the end of the experiment (d 21), TUM increased ($P = 0.02$; quad) BW, ADG, and ADFI of the barrows. For G:F, there was a linear ($P = 0.03$) increase

for pigs fed TUM compared with pigs fed the control, where pigs fed TUM had the most efficient G:F. All pigs fed TUM were heavier (P = 0.03), gained more weight (P = 0.02), tended to consume more feed (P = 0.10), and had a better (P = 0.02) G:F than pigs fed the control diet. The pigs fed 4 g/kg of TUM were the heaviest pigs, gained the most weight, consumed the most feed, and had the highest G:F.

Turmeric consumption (mg/kg of BW/d) increased (P < 0.0001; linear) as increasing levels were supplemented to the diet (Table III.3). Turmeric consumption was 0, 89.7, 181, and 354 mg/kg of BW/d for the treatments 0, 2, 4, & 8, respectively. Analyzed curcumin consumption increased (P < 0.0001) linearly as TUM increased in the diet (Table III.3). The curcumin consumed for the treatments 0, 2, 4, and 8 mg/kg was 0, 2.1, 4.4, and 8.3 mg/kg of BW/d, respectively.

LPS Challenge – Growth Performance

Growth was impeded during the LPS challenge. All pigs lost BW during the immune challenge. There was a cubic (P < 0.02) effect for h 3, 6, 12, and 24 post-injection (PI), where all pigs lost body mass (Table III.4). In respect to treatments, pigs fed 4 g/kg lost the least amount of BW for h 3, 6, 12, and 24 PI, while pigs fed 2 g/kg lost the most BW. For h 12 PI, all pigs consuming TUM tended (P = 0.06) to lose more weight than pigs not consuming TUM. Pigs fed control, and 4 and 8 mg/kg of TUM gained (P = 0.004; cubic) their BW back by h 24 PI; however, pigs consuming 2 g/kg of TUM did not. Pigs were fed 0.907 kg

of their assigned dietary treatment between h 12 and 24 PI. Feed intake was calculated after h 24 PI. There was no effect (P > 0.10) observed on feed intake (Table III.3).

LPS Challenge – Rectal Temperatures and Blood Analytes

There were no effects (P > 0.10) for h 0 or h 3, 6, 12, or 24 PI of feeding TUM on rectal temperature (Table III.5). However, a trend (P = 0.08) was observed for h 6 PI where all pigs fed TUM had higher rectal temperatures compared to pigs the control. Temperature peaked at h 3 PI for all dietary treatments. At this time point, pigs fed 2 g/kg TUM had the lowest numerical temperature and the control pigs had the highest numerical temperature.

There was an hour effect (P < 0.0001) for changes in rectal temperature, where the highest difference was at h 3 PI and decreased until to normal by h 24 PI (Figure III.1). There were no other differences (P > 0.10) observed for changes in rectal temperature. Numerically, pigs fed 2 g/kg TUM had the lowest change in temperature for h 3 PI. By h 24 PI, all temperatures had returned to normal.

Tumor necrosis factor-α is a pro-inflammatory cytokine that is used to determine an immune response. There was a tendency (P = 0.07; linear) for h 0 where TNF-α decreased as TUM increased in the diet (Table III.5). All pigs fed TUM tended (P = 0.10) to have lower levels of TNF-α than pigs not fed TUM for h 3 PI. Numerically, pigs fed 2 mg/kg of TUM had the lowest concentration. Peak

TNF-α was at h 3 PI. For h 24 PI, pigs the control tended (P = 0.09) to have higher levels of TNF-α than all pigs fed TUM for h 24 PI.

For changes in TNF-α, there was an hour effect (P < 0.0001; Figure III.2). At h 3 PI, pigs fed 2 mg/kg of TUM had the smallest (P = 0.0001) increase in change in TNF-α, followed by pigs fed 4 and 8 mg/kg of TUM, and then pigs fed the control diet. The pattern for changes in TNF-α was the same as rectal temperatures, with the greatest change observed at h 3 PI. There were no differences (P > 0.10) observed for h 6 and 24 PI.

An hour effect (P < 0.0001) was observed, where changes in CRP increased in a time-dependent manner. There were no differences (P > 0.10) observed for CRP (Table III.5). Levels of CRP peaked at h 24 and pigs fed 8 g/kg of TUM had the lowest numerical concentration at h 24 PI. No differences (P > 0.10) for changes in CRP were detected for h 3 or 6 PI (Figure III.3), but at h 24 PI, pigs fed 4 g/kg of TUM had the largest increase (P = 0.05) in CRP compared to the pigs fed the control, 2 g/kg of TUM and 8 g/kg of TUM.

No differences (P > 0.10) were noted for BUN due to TUM supplementation (Table III.5). Levels peaked at h 24 PI. All pigs fed TUM tended (P = 0.08) to have higher levels of BUN at h 24 PI than pigs fed the control.

An hour effect (P < 0.0001) was observed for changes in BUN, where changes in BUN increased in a time-dependent manner (Figure III.4). No differences (P > 0.10) were observed for h 3 and 6 PI. At h 24 PI, pigs fed the

control had a smaller change from h 0 (P = 0.03) when compared to pigs fed 8 mg/kg of TUM with pigs fed 2 and 4 mg/kg of TUM being intermediate.

At h 0, pigs fed TUM had higher (P = 0.001; quad) levels of glucose compared with pigs fed the control (Table III.5). When all TUM treatments were compared to the control, TUM increased (P = 0.003) glucose levels at h 0. Turmeric increased (P = 0.05; quad) glucose concentrations at h 3 PI. All pigs fed TUM tended (P = 0.10) to have higher levels of glucose in contrast to pigs fed the control diet. No differences (P > 0.10) were observed for h 6 and 24 PI.

There was an hour effect (P = 0.0002) for changes in glucose. When looking at changes in glucose, pigs fed the control had the least (P = 0.01) change compared with pigs fed 2 or 8 g/kg of TUM with pigs fed 4 g/kg of TUM intermediate at h 3 PI (Figure III.5). Changes in glucose decreased until h 6 PI and then started to increase to h 24 PI. No other differences (P > 0.10) were observed for changes in glucose levels.

Serum total protein was also measured. Pigs fed TUM had higher (P = 0.04; quad) levels of total protein than pigs fed the control at h 0 (Table III.5). No differences (P > 0.10) were observed for h 3, 6, or 24 PI. When compared to h 0, total protein decreased by h 24 PI. There was an hour effect (P = 0.0004) observed, but no differences (P > 0.10) were noted for changes in total protein for all treatments (Figure III.6).

There was a tendency (P = 0.08; linear) for pigs fed the control to have lower triglyceride levels at h 0 when compared with pigs fed TUM (Table III.5).

No differences (P > 0.10) were noted at h 3 PI for triglyceride levels. At h 6 PI, pigs fed TUM tended (P = 0.07; cubic) to have higher levels than pigs the control. By h 24 PI, pigs fed the control had higher (P = 0.04; cubic) concentrations of triglycerides than pigs fed TUM.

No hour effect (P = 0.20) was observed for changes in triglycerides (Figure III.7). There were no differences (P > 0.10) for changes in triglycerides for h 3 or 6 PI. Pigs fed the control diet tended (P = 0.09) to have a greater increased at h 24 PI than pigs fed 8 g/kg of TUM with 2 and 4 g/kg being intermediate.

DISCUSSION

When formulating the diets, the turmeric consumed on a mg/kg of BW/d was below, above, and equal to 176 mg. The pigs fed the 4 g/kg of TUM consumed a calculated 187 mg/kg of BW/d. This is similar to the expected levels. The 2 and 8 mg/kg of TUM were below and above 176 mg/kg of BW/d. The pigs consuming those diets were 89.7 and 352 mg/kg of BW/d of calculated turmeric, respectively. Therefore, pigs were consuming the turmeric concentrations that were calculated.

Little research has been published in regards to feeding turmeric to swine. Ilsley et al. (2005) reported no effect on growth performance in nursery pigs fed 200 mg/kg of curcumin. This is not in accordance with the current study. In fact, the dietary treatment containing 8 g/kg of TUM has a similar concentration of curcumin as the Ilsley et al. (2005) study, 188 mg/kg of analyzed curcumin vs.

200 mg/kg of curcumin. Turmeric increased ADG quadratically and increased G:F linearly; therefore, the pigs fed 8 g/kg of TUM had improved growth performance when compared with a control diet with no antibiotics. The differences observed in our study and Ilsley et al. (2005) could be that there were some growth enhancing components present in the turmeric that was not present in the curcumin in the study by Ilsley et al. (2005).

No adverse effects were noted in any of the pigs fed turmeric in this study. However, Bille et al. (1985) reported adverse effects on gain and feed efficiency in pigs fed 1551 mg/kg of BW/d of turmeric oleoresin. In the same study, as turmeric intake increased, thyroid and liver weights increased. The curcumin intakes for the turmeric oleoresin study were 10.5, 51.8, and 271.4 mg of curcumin/kg of BW, respectively, which are higher concentrations compared to our present experiment. Pigs consumed 2.1, 4.4, and 8.3 mg/kg of BW/d in the present study. Therefore, the differences observed between Bille et al. (1985) and the current experiment could be curcumin intake, where there was an antagonistic effect of high curcumin intake on growth performance and organ weight in the Bille et al. (1985) study.

Maneewan et al. (2012) reported an increase in nutrient digestibility of crude protein, crude fat, crude fiber, ash, and biological value of protein in pigs fed increasing levels of turmeric (0%, 0.05%, 0.10%, and 0.20%). The higher levels of turmeric had the highest levels of digested nutrients. However, there were no differences observed in growth performance for pigs fed turmeric when compared to a control with no antibiotics (Maneewan et al., 2012). It is possible

that pigs fed turmeric in this study had an increase in nutrient digestibility, which produced the quadratic increase in ADG and linear increase in G:F.

Weaning is a stressful event for nursery pigs and placing them in individual crates adds even more stress. Another stressful occurrence is traveling pressure. Wei et al. (2010) reported feeding pigs 8 mg/kg of curcumin helped alleviate traveling stress. The pigs fed curcumin had a decrease in hippocampal nitric oxide production, serum cortisol concentration, and an increase in mRNA expression of brain-derived neurotrophic factor after traveling on the road for 2 hours. There was also a reduction observed in the following enzymes: total nitric oxide synthase (NOS), constitutive NOS (cNOS), and inducible NOS (iNOS), as well as, a decrease in the expression of cNOS in the pigs administered curcumin (Wei et al., 2010). Even though cortisol or nitric oxide was not measured in this study, it is possible the curcumin present in the turmeric powder fed assisted in reducing stress during the immune challenge.

A viral infection also causes stress in pigs. After a porcine reproductive and respiratory syndrome (PRRS) virus infection, nursery pigs fed 10 mg/kg of turmeric oleoresin had better G:F than control pigs (Liu et al., 2013a). This can be related back to the current data. All pigs fed TUM had a heavier final BW, gained more weight and consumed more feed per day, and had a higher G:F compared to pigs fed the control. Therefore, a possible explanation for the increase in performance could be that the pigs fed TUM responded better to the stress of weaning. Liu et al. (2013a) and the pigs in this current study were in a

stressed environment where weight loss is common and turmeric helped increase performance during that stressful period.

A LPS challenge is a model used to study the effects of a variable on the immune response; therefore, a LPS challenge was utilized to study the effects of turmeric on innate immunity. Moya et al. (2006) stated that a few of the symptoms of a lipopolysaccharide challenge were fever, anorexia, and decreased activity. The *Escherichia coli* O111:B4 lipopolysaccharide administered in this study has been shown to elicit an innate immune response in nursery pigs (Mandali et al., 2000; Mandali et al., 2002; Smith, 2006; Bible, 2009; Williams et al., 2009).

The outer membrane, cell wall component, LPS, affects the animal immunologically as live bacteria would (Mandali et al., 2002). The Gram-negative bacterial LPS will activate the toll-like receptor 4 (TLR4). The stimulation of swine cells via LPS occurs using several different proteins. The soluble shuttling protein, LPS binding protein (LBP), binds LPS and carries it to cluster of differentiation (CD14). Lipopolysaccharide binds to CD14, which helps move the LPS to the TLR4/MD-2 (myeloid differentiation protein 2) complex. This binding initiates a downstream signaling that leads to the activation of the pro-inflammatory cytokines, such as TNF-α, via NF-κB pathway (Lu et al., 2008; Bryant et al., 2010). The inflammatory cytokines produced are released from macrophages and neutrophils (Moya et al., 2006).

The cytokines activate the metabolism of arachidonic acid leading to the production of COX (Lantz et al., 2005). A product of COX is prostaglandin E2 (PGE2). This molecule induces thermal activation or a fever. Thus, LPS also acts as a pyrogen or fever inducer (Ogoina, 2011). Fever is an indication that an immune response occurred (Van Gucht et al., 2004). The *E. coli* LPS model in the current study induced fever, initiated anorexia, and activated TNF-α, thus an innate immune response. Fever was observed at h 3 PI in the current experiment. At h 3 PI, pigs fed turmeric had numerically lower rectal temperatures compared to pigs fed the control.

The current study has a similar TNF-α response as other research. An *E. coli* O111:B4 LPS challenge (25 μg/kg of BW) increased the pro-inflammatory cytokines interleukin-6 (IL-6), interleukin-1β (IL-1β), and TNF-α in a time-dependent manner. The peak hours for IL-6, IL-1β, and TNF-α were 2.5 h, 3 h and, 1 h post-LPS, respectively (Williams el al., 2009). Webel et al. (1997) reported after 2 hours of an intraperitoneal injection of 5 μL/kg of body weight of LPS *E. coli* K-235, TNF-α was elevated 10-fold and interleukin-6 (IL-6) was elevated 200-fold by hour 4 of the challenge. The peak TNF-α response in this study was at h 3 PI, which is similar to that reported by Williams et al. (2009) and Webel et al. (1997).

In previous studies, curcumin has been shown to attenuate a LPS response by inhibiting or decreasing the pro-inflammatory cytokines (Sompamit et al., 2009). A possible mechanism for lower TNF-α concentration could be because the curcumin in the dietary turmeric inhibited the binding of LPS.

Curcumin has the ability to bind to MD-2. The MD-2 protein is involved in the TLR4/MD-2 complex that binds to CD14, and CD14 binds LBP, which binds LPS (Gradisar et al., 2007). Therefore, less LPS binding leads to less inflammation and a decrease in pro-inflammatory cytokines. As turmeric increased in the diet in this current study, TNF-α concentrations were blunted less at h 3 PI. A plausible explanation is that one of the other curcuminoids could be competing for the same binding site as curcumin since the chemical structures are similar. Or curcumin could be directly inhibiting the binding of NF-κB to DNA (Zhong et al., 2011). However, it might not be curcumin alone that helps inhibit the immune response. The other curcuminoids could have some effect on the immune system (Zhang et al., 2008). The exact mechanism of turmeric is not completely understood.

This study has similar results as reported by Lantz et al. (2005), Liu et al. (2013a) and Liu et al. (2013b), where turmeric blunted TNF-α. Lantz et al. (2005) demonstrated that curcumin and an organic extract of turmeric are capable of inhibiting TNF-α and PGE_2. Liu et al. (2013b) reported a reduction in TNF-α in pigs fed 10 mg/kg of turmeric oleoresin compared to control pigs fed no antibiotics during an experimentally infected *E. coli* challenge. Another study by Liu et al. (2013a) also reported similar results in pigs infected with PRRS virus consuming 10 mg/kg of turmeric oleoresin. Pigs fed TUM in the current study had lower concentrations of TNF-α than pigs fed a non-antibiotic control with pigs fed 2 g/kg of TUM having the smallest change in the pro-inflammatory cytokine.

Blood analytes BUN, glucose, total protein, and triglycerides were measured during the LPS challenge. Webel et al. (1997) reported an increase in plasma urea nitrogen (PUN) during a LPS challenge. Urea nitrogen is an indicator of protein degradation in starving or food-deprived animals. The inflammatory cytokine TNF-α can also increase muscle catabolism (Webel et al., 1997). Similar results were reported in this study. Pigs had increasing levels of BUN after an increase in TNF-α during a short period of food deprivation. Turmeric tended to increase BUN levels when compared to a control diet at h 24 PI. Turmeric decreased TNF-α, thus this would result in less protein catabolism and a lower BUN. However, this is not was observed in our study. The exact reasoning as to why turmeric increased BUN is not completely understood.

A decrease in glucose and an increase in triglycerides were observed in the current experiment due to the LPS challenge, which is similar to results reported by Webel et al. (1997). Turmeric had higher glucose levels and lower triglyceride levels during the LPS challenge. Curcumin has been shown to help control glucose in diabetes. Research has also reported curcumin can act on the pancreas (Bengmark et al., 2009); therefore, it is possible that the curcumin present in the turmeric acted on the pancreas to regulate blood glucose. Blood glucose is can be regulated by the catabolism of proteins and oxidation of fatty acids. This would result in an increase in BUN (protein) and triglycerides (fatty acids). Most of the changes in the blood analytes BUN, glucose, and triglycerides were due to the inflammation caused by the LPS (Webel et al.,

1997). Pigs were not allowed to consume any feed until 12 h PI, in which the pigs were fed 0.907 kg of their dietary treatment.

The acute phase protein, CRP, is activated in the liver by TNF-α (Liu et al., 2013b). With a half-life of 12 hours, CRP decreases after an immune response. Peak CRP concentrations are dependent on 4 actions: 1. Synthesis and liberation of TNF-α, 2. TNF-α interaction with the liver cells, 3. CRP production by the hepatocytes, and 4. the accumulation of CRP in the blood (Moya et al., 2006). As stated earlier, TNF-α increases protein catabolism. The amino acids released during this catabolism are believed to aide in synthesis of acute phase protein by providing fuel for the hepatocytes. The acute phase proteins may increase by 25% or more after an infection (Webel et al., 1997).

Williams et al. (2009) reported CRP levels started increasing at h 6 PI and continued to increase to h 24 PI. These results are similar to the current study where peak CRP concentrations were observed at h 24 PI. However, Moya et al. (2006) reported peak TNF-α concentrations at h 2 PI with a corresponding peak in CRP concentrations at h 12 PI. In the current study, the peak TNF-α concentrations were 3 hours after injection and peak CRP levels at 24 h PI. Therefore, it is possible that, in this experiment, the peak CRP levels were missed due to the short half-life of CRP. Turmeric had no effect on CRP levels in this study.

CONCLUSION

In conclusion, turmeric supplementation increased growth performance compared to a control diet containing no antibiotics or zinc. Turmeric also decreased the response of a LPS challenge by lowering rectal temperature and change in TNF-α. Turmeric at 2 g/kg of the diet increased growth performance over 21 days and decreased rectal temperature and TNF-α during a LPS challenge. Therefore, further research should be conducted to study the effects of turmeric at 2 g/kg of the diet vs. subtherapeutic antibiotics in a commercial nursery setting.

Table III.1. Nutrient composition of the control diet[a]

Ingredients	**%**
Corn	26.84
Soybean meal, dehulled	13.28
Whey, dried	20.00
Lactose	10.00
Fishmeal, menhaden	5.00
Soy protein concentrate	12.00
Plasma, spray-dried	6.00
L-lysine HCl	0.20
DL-methionine	0.15
Soybean oil	4.00
Dicalcium phosphate	0.72
Limestone	0.91
Salt	0.50
Vitamin premix[b]	0.25
Trace mineral premix[c]	0.15
TOTAL	100.00

Calculated analysis:	
ME, kcal/kg	3536
Dry mater, %	91.9
Crude protein, %	26.7
SID Lysine, %	1.44
Calcium, %	1.01
Available phosphorus, %	0.56

[a]Turmeric powder added at 2, 4, and 8 g/kg, respectively, to the control diet.
[b]Provided on a per kg basis: 11023 IU of vitamin A as vitamin A acetate, 1653 IU of vitamin D_3, 44.1 IU of vitamin E as vitamin E acetate, 4.41 mg of vitamin K as menadione bisulfate, 0.0441 mg of vitamin B_{12}, 9.92 mg of riboflavin; 33.1 mg of pantothenic acid as d-Cal pantothenic acid, 55.1 mg of niacin as nicotinic acid.
[c]Provided on a per kg basis: 165 mg of zinc as zinc sulfate, 165 mg of iron as iron sulfate, 39.7 mg of manganese as manganese oxide, 16.5 mg of copper as copper sulfate, 298 mg of iodine as calcium iodate, 298 mg of selenium as sodium selenite.

Table III.2. Calculated curcuminoid concentrations of turmeric powder[a] fed to nursery barrows

Turmeric (g/kg of diet)	Curcuminoid (mg/kg of diet)		
	CUR[b]	DMC[c]	BDMC[d]
2	47.2	20.8	13.8
4	94.4	41.6	27.6
8	188.8	83.2	55.2

[a]Turmeric powder = 2.36% curcumin, 1.04% demethoxycurcumin, and 0.69% bisdemethoxycurcumin.
[b]CUR = curcumin.
[c]DMC = demethoxycurcumin.
[d]BDMC = bisdemethoxycurcumin.

Table III.3. Effects of increasing levels of turmeric powder on growth performance of nursery barrows[a]

	Turmeric, g/kg[b]					P =			
	0	2	4	8	SE	Lin	Quad	Cub	C vs T[c]
BW, kg									
d 0	7.5	7.6	7.5	7.3	0.12	0.19	0.43	0.59	0.85
d 7	8.7	8.9	8.9	8.4	0.18	0.24	0.21	0.98	0.95
d 14	10.6	11.4	11.7	10.8	0.22	0.77	0.02	0.92	0.01
d 21	14.8	15.8	16.4	15.4	0.37	0.37	0.02	0.73	0.03
ADG, g/d									
d 0-7	177	181	200	165	16.6	0.66	0.26	0.55	0.77
d 7-14	286	387	440	364	29.7	0.15	0.007	0.91	0.006
d 14-21	569	587	627	620	32.1	0.26	0.54	0.67	0.28
d 0-21	350	389	426	388	16.7	0.16	0.02	0.58	0.02
ADFI, g/d									
d 0-7	239	258	277	246	9.8	0.74	0.02	0.54	0.08
d 7-14	368	442	454	405	22.1	0.49	0.02	0.65	0.02
d 14-21	739	736	799	727	33.5	0.93	0.26	0.30	0.71
d 0-21	458	487	518	466	15.7	0.82	0.02	0.50	0.10
G:F									
d 0-7	0.732	0.692	0.715	0.684	0.05	0.62	0.94	0.64	0.57
d 7-14	0.774	0.867	0.969	0.847	0.05	0.34	0.03	0.51	0.04
d 14-21	0.771	0.806	0.777	0.855	0.03	0.13	0.61	0.38	0.30
d 0-21	0.762	0.798	0.820	0.830	0.02	0.03	0.31	0.97	0.02
Turmeric Consumed, mg/kg BW/d									
	0	89.7	187	352	7.04	<0.0001	0.36	0.54	<0.0001
Curcumin Consumed, mg/kg BW/d									
	0	2.1	4.4	8.3	0.17	<0.0001	0.36	0.54	<0.0001

[a]Least squares means for 8 barrows/treatment.
[b]0 = control diet (CNT); 2 = CNT + 2 g/kg turmeric powder; 4 = CNT + 4 g/kg turmeric powder; 8 = CNT + 8 g/kg curcumin powder.
[c]C vs T = control versus all turmeric treatments.

Table III.4. Effects of increasing levels of turmeric powder on growth performance of nursery barrows during a LPS[a] challenge[b]

	Turmeric, g/kg[c]					P =			
	0	2	4	8	SE	Lin	Quad	Cub	C vs T[d]
% BW of h 0									
h 3	97.9	96.6	98.4	98.1	0.45	0.28	0.82	0.01	0.76
h 6	97.5	94.9	97.3	97.1	0.64	0.58	0.29	0.01	0.20
h 12	96.1	93.3	95.4	94.8	0.69	0.65	0.26	0.02	0.06
h 24	101.8	94.8	102.4	99.6	1.46	0.92	0.56	0.001	0.12
FI[e], g									
h 12-24	450	529	359	509	91	0.87	0.60	0.29	0.90

[a]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[b]Least squares means for 8 barrows/treatment.
[c]0 = control diet (CNT); 2 = CNT + 2 g/kg turmeric powder; 4 = CNT + 4 g/kg turmeric powder; 8 = CNT + 8 g/kg turmeric powder.
[d]C vs T = control versus all turmeric treatments.
[e]Between h 12 and h 24 pigs were fed 0.907 kg of their assigned treatment.

Table III.5. Effects of increasing levels of turmeric powder on rectal temperature and blood analytes of nursery barrows during a LPS[a] challenge[b]

	Turmeric, g/kg[c]					P =			
	0	2	4	8	SE	Lin	Quad	Cub	C vs T[d]
Rectal temperature, °C									
h 0	39.7	39.7	39.8	39.6	0.11	0.58	0.19	0.54	0.74
h 3	41.0	40.6	40.8	40.9	0.14	0.99	0.24	0.11	0.17
h 6	40.3	40.6	40.8	40.7	0.17	0.15	0.24	0.87	0.08
h 12	40.4	40.4	40.6	40.4	0.18	0.99	0.48	0.57	0.77
h 24	39.4	39.6	39.5	39.6	0.11	0.56	0.83	0.37	0.39
TNF-α[e], pg/mL									
h 0	53.5	46.3	37.4	36.2	6.26	0.07	0.42	0.76	0.08
h 3	2434	782	1518	1675	536.8	0.68	0.18	0.18	0.10
h 6	621	315	555	565	136.7	0.77	0.47	0.18	0.43
h 24	100	58.3	54.7	41.5	22.82	0.13	0.46	0.64	0.09
CRP[f], mg/mL									
h 0	1.8	1.9	0.97	1.6	0.35	0.52	0.30	0.15	0.50
h 3	1.8	1.7	1.1	1.5	0.34	0.42	0.33	0.41	0.34
h 6	2.0	2.1	1.4	1.9	0.27	0.73	0.36	0.22	0.66
h 24	4.3	4.5	4.5	3.7	0.56	0.43	0.46	0.94	0.95
BUN[g], mg/dL									
h 0	10.8	11.1	11.6	9.6	1.03	0.45	0.34	0.74	0.98
h 3	10.7	10.1	9.5	10.1	1.14	0.74	0.56	0.86	0.56
h 6	12.0	13.3	11.7	12.2	1.12	0.91	0.92	0.35	0.77
h 24	12.5	14.1	14.6	14.9	0.90	0.11	0.39	0.82	0.08
Glucose, mg/dL									
h 0	114	134	132	126	3.0	0.12	0.001	0.08	0.003
h 3	99	117	124	107	8.1	0.71	0.05	0.99	0.10
h 6	109	96	108	85	9.1	0.16	0.65	0.25	0.31
h 24	106	111	118	111	6.0	0.59	0.27	0.71	0.32
Total protein, g/dL									
h 0	5.4	5.7	5.6	5.4	0.10	0.64	0.04	0.35	0.15
h 3	5.1	5.3	5.2	5.2	0.16	0.77	0.73	0.46	0.49
h 6	5.2	5.3	5.4	5.0	0.14	0.24	0.20	0.71	0.96
h 24	5.0	5.0	5.1	5.0	0.17	0.91	0.58	0.80	0.71
Triglycerides, mg/L									
h 0	29	41	43	33	5.7	0.83	0.08	0.78	0.14
h 3	45	45	42	47	9.3	0.88	0.78	0.87	0.97
h 6	35	58	40	52	7.8	0.39	0.67	0.07	0.15
h 24	48	34	48	39	4.8	0.59	0.93	0.04	0.25

[a]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[b]Least squares means for 8 barrows/treatment.
[c]0 = control diet (CNT); 2 = CNT + 2 g/kg turmeric powder; 4 = CNT + 4 g/kg turmeric powder; 8 = CNT + 8 g/kg turmeric powder.
[d]C vs T = control versus all turmeric treatments.
[e]TNF-α = tumor necrosis factor-α.
[f]CRP = C-reactive protein.
[g]BUN = blood urea nitrogen.

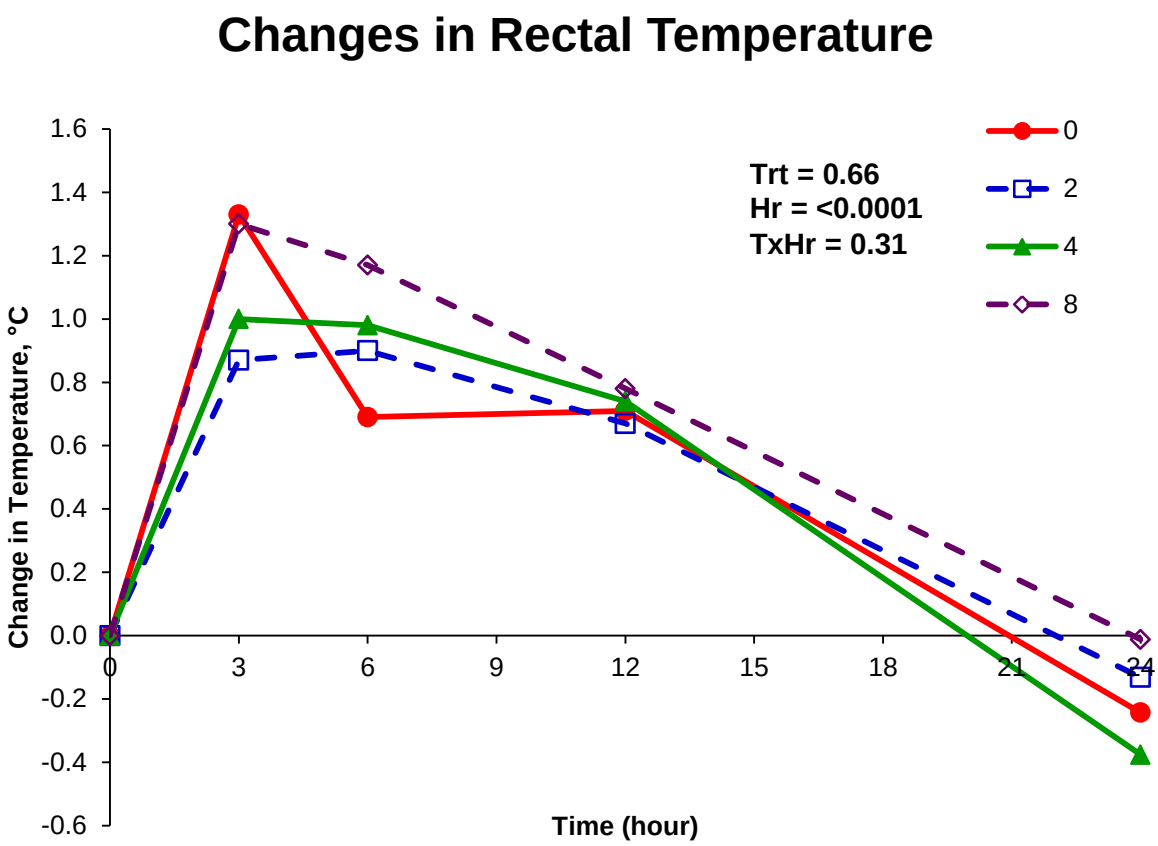


Figure III.1. Effects of turmeric powder on changes in rectal temperature of nursery barrows during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no turmeric; □ – 2 g/kg of turmeric; ▲ – 4 g/kg of turmeric; ◊ – 8 g/kg of turmeric. There were 8 barrows/treatment.

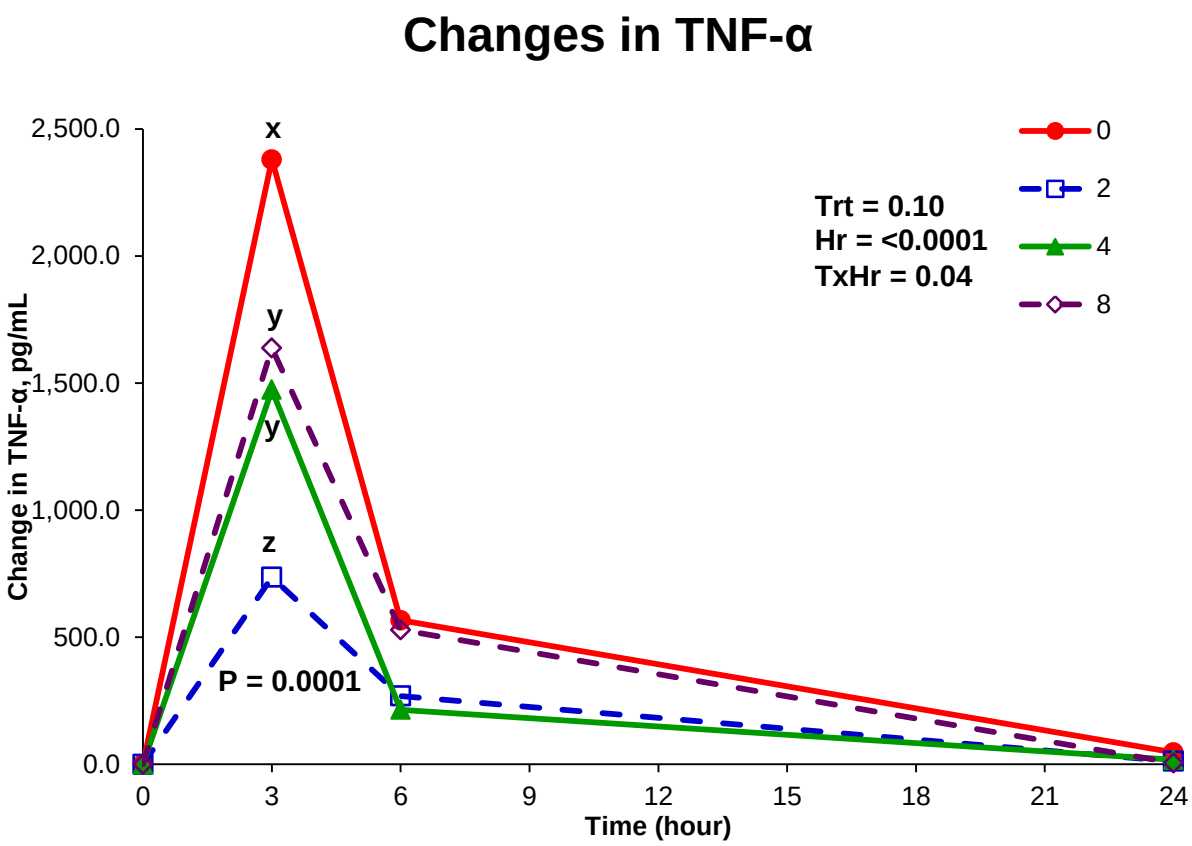


Figure III.2. Effects of turmeric powder on changes in tumor necrosis factor-α (TNF-α) of nursery barrows during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no turmeric; □ – 2 g/kg of turmeric; ▲ – 4 g/kg of turmeric; ◊ – 8 g/kg of turmeric. There were 8 barrows/treatment.

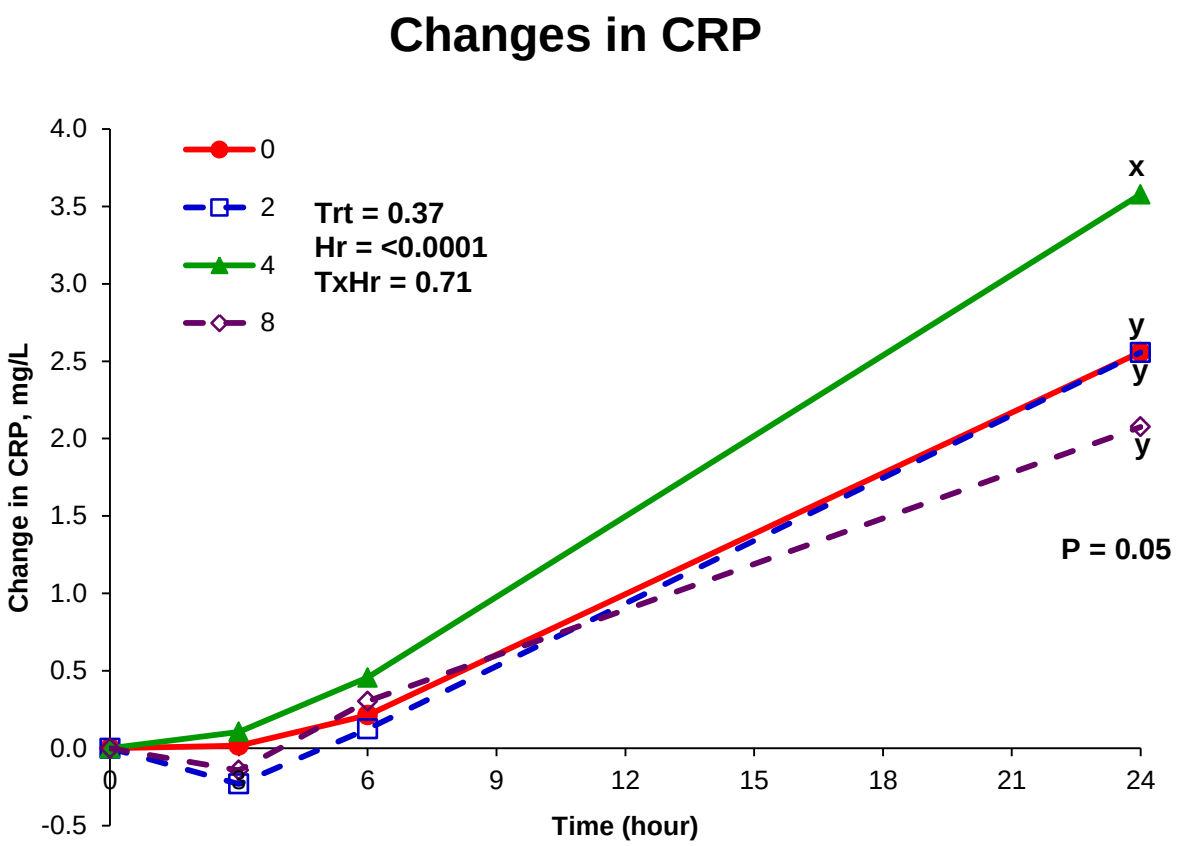


Figure III.3. Effects of turmeric powder on changes in C-reactive protein (CRP) of nursery barrows during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no turmeric; □ – 2 g/kg of turmeric; ▲ – 4 g/kg of turmeric; ◊ – 8 g/kg of turmeric. There were 8 barrows/treatment.

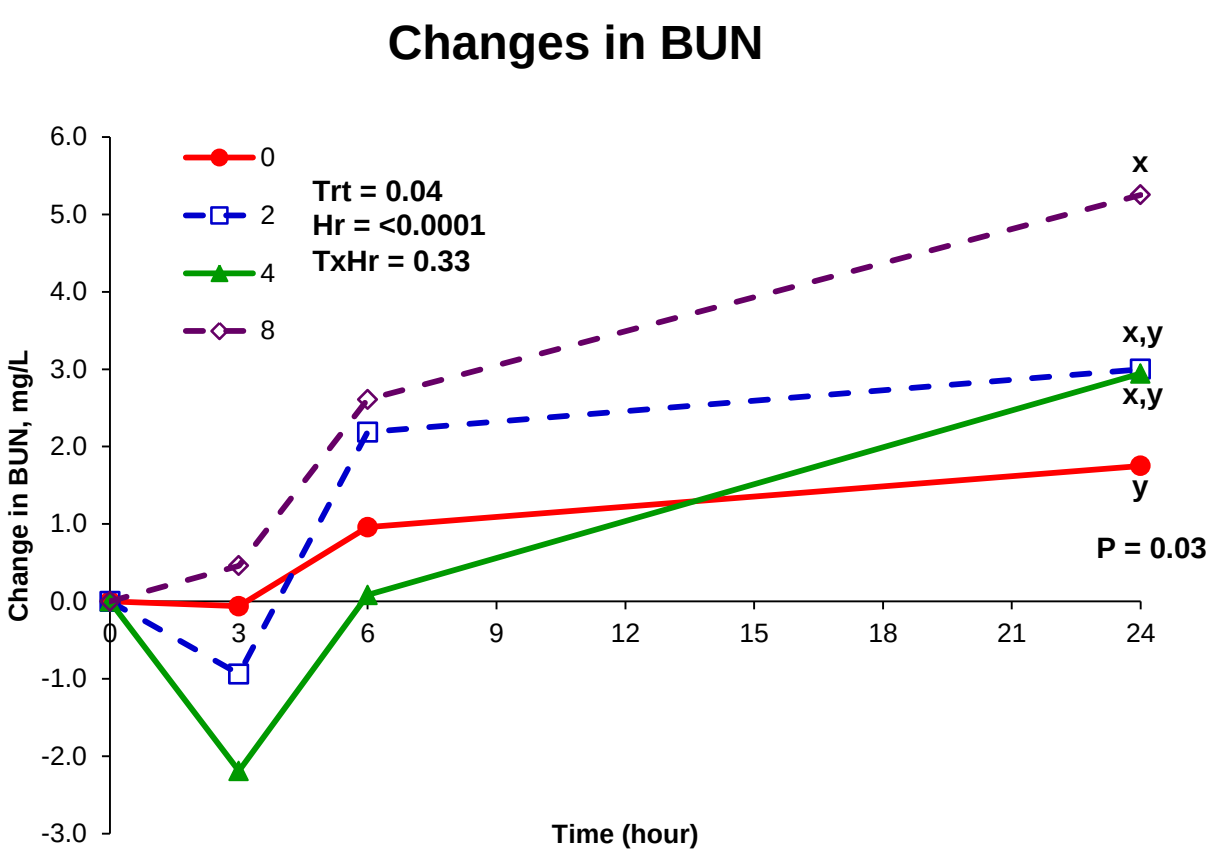


Figure III.4. Effects of turmeric powder on changes in blood urea nitrogen (BUN) of nursery barrows during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no turmeric; □ – 2 g/kg of turmeric; ▲ – 4 g/kg of turmeric; ◊ – 8 g/kg of turmeric. There were 8 barrows/treatment.

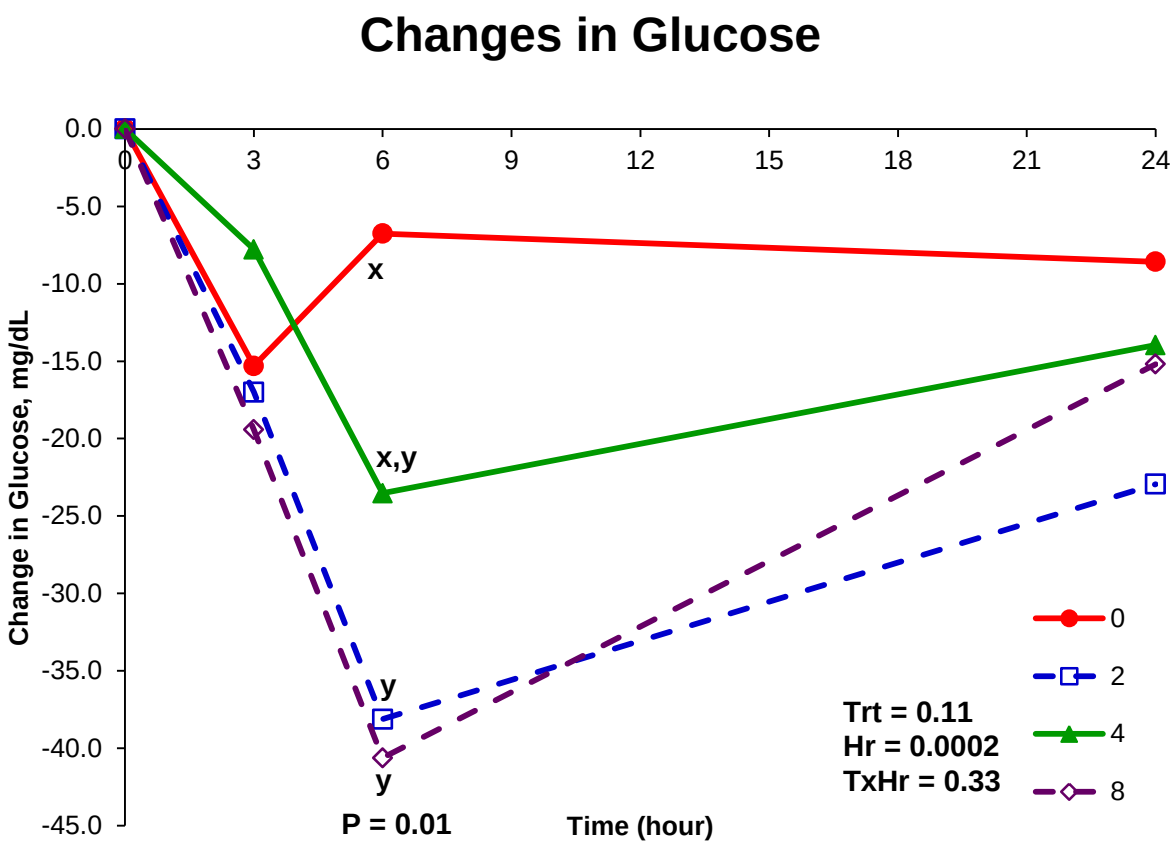


Figure III.5. Effects of turmeric powder on changes in glucose of nursery barrows during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no turmeric; □ – 2 g/kg of turmeric; ▲ – 4 g/kg of turmeric; ◊ – 8 g/kg of turmeric. There were 8 barrows/treatment.

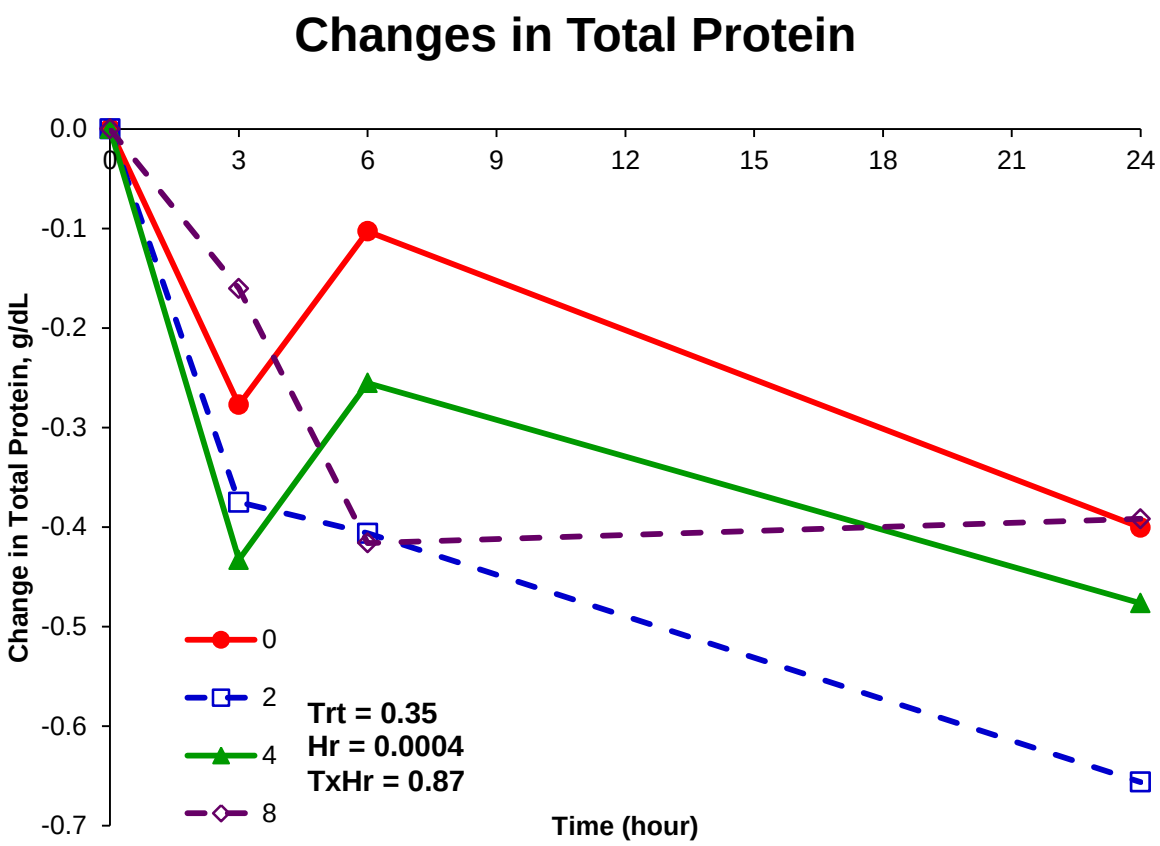


Figure III.6. Effects of turmeric powder on changes in total protein of nursery barrows during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no turmeric; □ – 2 g/kg of turmeric; ▲ – 4 g/kg of turmeric; ◊ – 8 g/kg of turmeric. There were 8 barrows/treatment.

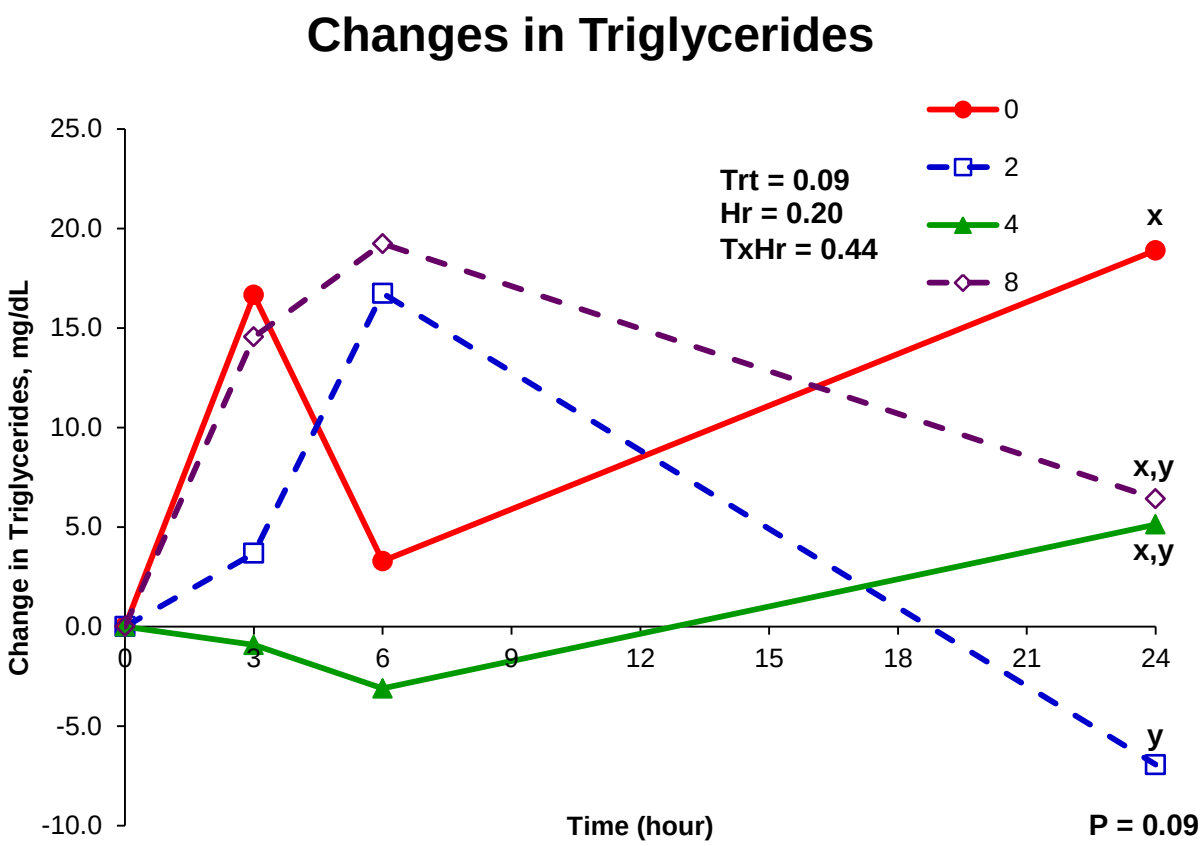


Figure III.7. Effects of turmeric powder on changes in triglycerides of nursery barrows during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no turmeric; □ – 2 g/kg of turmeric; ▲ – 4 g/kg of turmeric; ◊ – 8 g/kg of turmeric. There were 8 barrows/treatment.

CHAPTER IV

EXPERIMENT II

EFFECTS OF CURCUMIN SUPPLEMENTATION VS. CARBADOX ON GROWTH PERFORMANCE AND IMMUNE RESPONSE OF NURSERY PIGS

M. R. Bible, S. D. Carter, K. F. Coble, H. J. Kim, and T. M. Walraven

Oklahoma State University, Stillwater, OK

ABSTRACT

Curcumin is an active component in turmeric that has antimicrobial and anti-inflammatory properties, which may aid in improving growth performance of nursery pigs. Thus, 216 (5.8 kg; 8 reps/trt) crossbred (D x (L x Y)) pigs were used to determine the effects of curcumin on growth performance and immune response of nursery pigs. Pigs were weaned at 20 d of age, blocked by BW and stratified by ancestry, and allotted randomly to 4 dietary treatments in a randomized complete block design (RCBD). Standard corn-soybean meal-based diets were fed in meal form in a 4-phase feeding program (SID Lys 1.56, 1.51, 1.31, 1.25%). Diets were a negative control (no antibiotic; CNT), a positive control (carbadox, 55 mg/kg; AB), CNT + 2 g/kg of turmeric powder (TUM), and CNT + 80 mg/kg of curcumin powder (CUR). AB, TUM, and CUR replaced corn in the diets. ADG (g/d), ADFI (g/d), and G:F were calculated for d 0-21 and 0-42. On d 20, 1 pig/pen was challenged with *E. coli* lipopolysaccharide (LPS; 25 µg/kg BW intraperitoneal). Rectal temperatures (RT) were measured and blood collected for analysis of tumor necrosis factor-alpha (TNF-α), C-reactive protein (CRP), blood urea nitrogen (BUN), glucose, total protein, and triglycerides at 0, 3, 6, 12, and 24 hr post-injection (PI). Growth data were analyzed as a RCBD using a general linear model; immune response analysis used a mixed model with repeated measures. For d 0-21, pigs fed AB had greater ADG ($P = 0.02$) compared with pigs fed CNT or TUM, with pigs fed CUR intermediate. There were no differences ($P > 0.10$) observed for ADFI or G:F. The cost/gain/pig was similar for pigs fed AB, CUR, and CNT, but pigs fed TUM had a higher

cost/gain/pig. For d 0-42, pigs fed AB and CUR gained more weight (P = 0.0008) compared with pigs fed CNT and TUM with no differences (P > 0.10) being observed for ADFI or G:F. RT and TNF-α increased from hr 0, peaked at 3 hr, and returned to normal by 24 hr PI of LPS. Pigs fed CUR had the smallest increase (P < 0.0001) in TNF-α at hr 3 PI, followed by AB, CNT, and finally, TUM. Pigs fed CUR, TUM, and AB had the largest increase (P = 0.004) in CRP compared with pigs fed CNT at h 24 PI. In conclusion, pigs fed CUR had similar growth performance to AB and CUR blunted the response to a LPS challenge.

INTRODUCTION

Turmeric, *Curcuma longa* Linn, is a very prominent herbaceous spice used in Southeast Asian dishes (Tayyem et al., 2006; Bengmark et al., 2009) and is part of the ginger family or Zingiberaceae (Brewer, 2011). Curcumin is the most active component in turmeric and gives turmeric its yellow color (Lantz et al., 2005; Bengmark et al., 2009). Curcumin was discovered over two centuries ago by Vogel and Pelletier. They reported a “yellow coloring-matter” and named it curcumin. In 1910, Lampe and Milobedzka identified the structure of diferuloylmethane or curcumin (Gupta et al., 2012). The concentration of curcumin in turmeric is extremely variable, which is thought to be dependent on soil acidity and available nutrients to the plant (Tayyem et al., 2006). The average curcumin concentration in turmeric is between 4-5% (Bengmark et al., 2009).

There has been numerous research done with curcumin. Curcumin decreases tumor necrosis factor-α (TNF-α), cyclooxygenase (COX), NF-κB activation, C-reactive protein (CRP), and prostaglandin E2 (Rajasekaran, 2011). In humans, curcumin has alleviated symptoms associated with Crohn's disease, ulcerative colitis, ulcers, irritable bowel syndrome, and gastric inflammation, just to name a few (Gupta et al., 2013).

With all of the positive effects of subtherapeutic antibiotics, its use is a concern due to antibiotic resistant bacteria. It is estimated in the United States alone antibiotic-resistant bacteria have a yearly impact of $5-$24 billion (Ahmad et al., 2011). Subtherapeutic antibiotic use has been a concern since 1969 when a report by the Swann Committee was given to the English Parliament, to now, where some countries, like the European Union, have banned subtherapeutic antibiotics. After the initial banning in Denmark, there was an increase in the mortality of nursery pigs (Hogberg et al., 2009). Therefore, the use of antibiotics in feed may eventually be banned in the United States due to consumer perception.

The objective of this study was to determine the effects of curcumin supplementation versus a diet containing subtherapeutic antibiotic on growth performance, as well as, the immune response during an *Escherichia coli* lipopolysaccharide challenge in nursery pigs.

MATERIALS AND METHODS

Curcumin and Turmeric Analysis

The curcumin and turmeric powders were analyzed for curcumin, bisdemethoxycurcumin, and demethoxycurcumin concentrations. The analysis was performed by GAAS, Corporation (Tucson, AZ) using an HPLC. Briefly, samples were extracted with an 80:20 solvent mixture of methanol:water. Approximately 2 mL of the supernatant was transferred to an amber HPLC vial and injected into the column. The column type and size was a Kinetex C18, 2.6 µ, 150 x 4.6mm column. All standards used were greater than 91% pure.

Animal Care and Feeding

A total of 216 crossbred ((Duroc x (Landrace x Yorkshire)) nursery pigs were weaned at 20 d of age and used in a 42-d study. Pigs with an average weight of 5.8 kg were blocked by body weight, stratified by ancestry, and sex, and allotted randomly to one of four dietary treatments in a randomized complete block design (RCBD). The dietary treatments were: 1) a negative control diet containing no antibiotics (CNT), 2) a positive control diet containing 55 mg/kg of carbadox (AB), 3) control diet + 2 g/kg of turmeric powder (TUM), and 4) control diet + 80 mg/kg of curcumin powder (CUR). All diets met or exceeded the requirements listed in the Nutrient Requirements for Swine (NRC, 1998). The turmeric and 95% curcumin powders were purchased from Herbal Extracts Plus (Croydon, PA). Pigs were fed a four-phase feeding program (Tables IV.1-4). Phases 1, 2, 3, and 4 were fed at d 0-7, 7-14, 14-21, and 21-42, respectively. All

diets were balanced on SID lysine, calcium, and available phosphorus. The SID Lys for each phase was 1.56%, 1.51%, 1.31%, and 1.25%, respectively.

Growth performance (ADG, ADFI, and G:F) data were calculated from the weekly recording of BW and feed disappearance. Feed cost of each dietary treatment, cost per pig, and cost per gain per pig were calculated in U.S. dollars. All feed ingredient prices, except turmeric and curcumin, were obtained in January 2013 from Oklahoma State University's feed mill. Curcumin and turmeric prices were observed from Herbal Extract Plus.

Pigs were housed in an environmentally-controlled building similar to a commercial setting. Pigs were allowed to consume water and feed *ad libitum*. Each pen had a five-hole stainless steel feeder and a single cup/nipple waterer. There were 8 replications per treatment with 6 or 8 pigs/pen. All pigs were cared for and handled following the guidelines established by the Oklahoma State University Institutional Animal Care and Use Committee.

Blood Collection

At day 0 of the experiment, a pig from each pen was chosen based on the average weight of the pen to be used for the lipopolysaccharide challenge. Each treatment had 3 barrows and 3 gilts for a total of 6 replications per treatment. Blood samples from each pig were collected from the anterior vena cava (jugular) using a 20 gauge 3.8 cm vacutainer needle with a 10 mL sterile serum tube (BD, Franklin Lakes, NJ), while the pigs were in a supine position. Samples were collected at d 0, 7, 14, and 21. The d 0 collection was used as the baseline.

Each blood sample was placed on ice after collection and stored at 2-5°C overnight. Then, the samples were centrifuged for 20 minutes at 2,000 x *g* to separate the serum. Serum was collected using a plastic transfer pipet and aliquoted into appropriately labeled microcentrifuge tubes and stored at -20°C until further analyses.

Escherichia Coli Lipopolysaccharide Challenge

On day 20 of the experiment, each pig that was used for blood collection was subjected to a lipopolysaccharide (LPS) challenge. During the entire LPS challenge, the challenged pigs remained in their pens with their other pen mates. *Escherichia coli* O111:B4 LPS (Sigma-Aldrich, Co., St. Louis, MO) was suspended in 9 g/L of sterile saline to a final concentration of 25 μg/kg of BW. Before injection of the LPS, hour 0 baseline blood samples were taken and BW and rectal temperatures were recorded. Then, the LPS was administered intraperitoneally in the lower abdomen. Rectal temperature, activity score, and BW were recorded, as well as, blood was collected at 3, 6, 12, and 24 h post-injection. Rectal temperatures were collected to indicate an immune response had occurred and to calculate the change in temperature from h 0. Activity score was the following: 1 = inactive; 2 = moderately inactive; 3 = active; 4 = moderately active; 5 = highly active. Activity score was adapted from behavior descriptions by Hay et al. (2003). Briefly, inactive pigs were sleeping or lying, and showing the pain-related activities of prostrated, huddled up, stiffness, or trembling. Moderately inactive pigs were showing pain-related activities. Awake inactive described pigs those were active. Moderately active pigs were walking,

chewing, or licking. Active pigs were running, playing, and showing aggression (Hay et al., 2003). Body weights were used to calculate % BW of h 0.

Blood Serum Analysis

Serum samples from d 0, h 0 pre-LPS injection, and 3, 6, 12, and 24 h post-LPS injection were analyzed for TNF-α, CRP, BUN, glucose, total protein, and triglycerides. The change in each blood analyte was calculated using the h 0 time point. To test the concentrations of TNF-α, an enzyme-linked immunosorbent assay (ELISA) kit was used (R&D Systems, Inc., Minneapolis, MN). Serum samples were analyzed following the manufacturer's instructions. The 3 h post-injection samples were diluted 10-fold. The inter assay CV was 5.0% and the intra assay CV was 6.8%. Glucose, BUN, total protein, triglycerides, and CRP were analyzed using a Biolis24i Chemistry Analyzer (Carolina Liquid Chemistries Corp., Winston-Salem, NC). The intra-assay CV for CRP, BUN, glucose, total protein, and triglycerides were 6.5, 3.8, 2.1, 2.7, and 3.5%, respectively. Manufacturer's directions were followed. Calibrators, controls, and BUN, glucose, total protein, triglycerides, and CRP HS wide range reagents were purchased from VWR (Radnor, PA).

Statistical Analysis

All data were analyzed using a randomized complete block design (SAS Institute, version 9.2). Growth performance data, including LPS % BW of h 0, were analyzed using the PROC GLM procedure. All LPS challenge blood chemistry and rectal temperature data were analyzed using a repeated measures

analysis of variance. The first-order autoregressive covariance structure was implemented. Slice effect was used to test for any differences between treatments at different time points. Pen served as the experimental unit. The treatment means are presented as least squares means. Differences were considered significant at the $P < 0.05$ level and a trend was considered at $0.10 < P > 0.05$.

RESULTS

Curcuminoid Concentrations

The curcumin powder that was analyzed contained 58%, 12%, and 2% of curcumin, demethoxycurcumin (DMC), and bisdemethoxycurcumin (BDMC), respectively. The analyzed concentrations for the turmeric powder were 1.25%, 0.45%, and 0.34% of curcumin, DMC, and BDMC, respectively. Table IV.5 shows the calculated mg/kg of the curcuminoid concentrations for the CUR and TUM diets.

Growth Performance

All growth performance data are shown in Table IV.6. For d 21 BW, pigs fed AB weighed ($P = 0.02$) the more than pigs fed TUM, with pigs fed CUR and CNT being intermediate. For d 0-21, pigs fed AB gained ($P = 0.02$) more weight than pigs fed TUM, with pigs fed CUR and CNT being intermediate. No differences were observed for ADFI ($P = 0.15$) or G:F ($P = 0.11$). Pigs fed AB numerically consumed more feed/day than any other treatment and pigs fed CUR had the best numerical G:F for d 0-21.

For d 42 BW, pigs fed TUM and CNT were lighter (P = 0.0007) in contrast to pigs fed AB and CUR. Pigs fed AB and CUR had a higher (P = 0.0008) ADG than pigs fed TUM and CNT for d 0-42. There were no differences observed for ADFI (P = 0.43) or G:F (P = 0.27), But pigs fed AB numerically consumed more feed followed by pigs fed CNT and CUR, and lastly pigs fed TUM. Pigs fed CUR and AB had numerically greater G:F compared with pigs fed CNT and TUM

LPS Challenge – Rectal Temperature, Activity Score, and BW Lost

An hour effect (P < 0.0001) was observed for rectal temperature (Table IV.7). There were no differences (P > 0.10) observed for rectal temperature at h 0 or h 3, 6, 12, or 24 PI. However, all dietary treatments had acquired a fever at h 3 post-injection (PI). For changes in rectal temperature, an effect (P < 0.0001) of hour was observed. The greatest increase in rectal temperature was observed at h 3 PI, and then a decrease occurred until h 24 PI. Pigs fed CUR had a smaller change (P = 0.04) in rectal temperature at h 6 PI compared to pigs fed CNT with AB and TUM being intermediate (Figure IV.1). No differences (P > 0.10) were observed for h 3 or 24 PI.

Activity score data is listed in Table IV.7. An hour effect (P < 0.0001) was observed. The activity score follows the same pattern as the rectal temperatures, as rectal temperature increases, the activity of the pigs decrease. There were no differences for activity score (P > 0.10) at h 0 or h 3, 6, or 24 PI. At h 12 PI, pigs fed CUR were less (P = 0.05) active than pigs fed CNT with pigs fed AB and TUM similar. The lowest activity scores were h 6 PI. Just like rectal temperature at h 24 PI, activity score returned to normal.

If pigs are less active, then there is little likelihood of them consuming food. The % BW of h 0 follows the same pattern as activity scores (Table IV.7). During h 3 PI, pigs fed TUM and AB had a greater (P = 0.01) % loss compared with pigs fed CNT and CUR. Pigs fed CUR and CNT lost less (P = 0.02) weight than pigs fed AB and TUM at h 6 PI. For h 12 PI, pigs fed AB and TUM lost more (P = 0.007) % BW in contrast to pigs fed CUR with pigs fed CNT intermediate. For h 24 PI, no differences (P = 0.13) were observed for % BW of h 0.

LPS Challenge – Blood Analytes

There was an hour effect (P <0.0001) for TNF-α concentrations and changes in TNF-α. There was an increase in TNF-α during the LPS challenge. At h 3 PI, pigs fed CUR had the lowest (P < 0.0001) concentrations and changes from h 0 followed by pigs fed AB and then pigs fed CNT and TUM (Table IV.8 and Figure IV.2). The greatest increase in TNF-α was at h 3 PI and changes decreased until h 24 PI. There were no other differences (P > 0.10) observed for any other hour for TNF-α concentrations or changes from h 0.

The acute phase protein CRP is in response to TNF-α activation (Table IV.8). No differences (P > 0.10) were observed for h 0 or for h 3 and 6 PI. Pigs fed CNT had the lowest (P = 0.004) CRP concentrations at h 24 PI compared with pigs fed AB, CUR, or TUM. For changes in CRP from h 0, pigs fed AB had a larger (P = 0.004) change in contrast to pigs fed CNT for h 24 PI (Figure IV.3). Pigs fed CUR and TUM were intermediate. There were no other differences (P >

0.10) observed for changes in CRP for h 3 or 6 PI. Concentrations of CRP and changes in CRP increased ($P < 0.0001$) in a time-dependent manner.

Blood urea nitrogen is a measure of protein catabolism. No differences ($P > 0.10$) were observed for BUN levels or changes from h 0 (Table IV.8 and Figure IV.4). Urea nitrogen concentrations and changes in BUN increased ($P < 0.0001$) in a time-dependent manner with the highest levels observed at h 24 PI. At this time point, pigs fed TUM were numerically the highest followed by pigs fed AB and CNT then pigs fed CUR.

No differences ($P > 0.10$) were observed for h 0 or for h 6 and 24 PI for blood glucose levels. At h 3 PI, pigs fed CUR had the highest ($P = 0.009$) serum glucose concentration in contrast to pigs fed AB or TUM with pigs fed CNT being intermediate. There were no differences ($P > 0.10$) for changes in glucose levels for h 6 and 24 PI (Figure IV.5). Pigs fed CNT had the least ($P = 0.004$) change in glucose at h 3 PI compared with pigs fed CUR, TUM, or AB. There was also an hour effect ($P < 0.0001$), where glucose decreased over time.

No differences ($P > 0.10$) were observed for total protein concentrations or changes in total protein from h 0 (Figure IV.7). An hour effect was observed for total protein ($P = 0.007$) and changes in total protein ($P = 0.01$); where total protein decreased over time.

Serum triglyceride concentrations were not different ($P > 0.10$) for h 0 or for h 3, 6, and 24 PI (Table IV.8). Triglycerides ($P = 0.04$) and changes in triglycerides ($P = 0.03$) increased in a time-dependent manner. Pigs fed CUR

had the least (P = 0.04) change in triglyceride levels at h 24 PI compared to pigs fed AB, TUM, or CNT.

DISCUSSION

The turmeric concentration used for this experiment was determined from previous research in Chapter III. From that study, the concentration of 2 g of turmeric/kg of diet was chosen due to growth performance and immunomodulation properties. The average curcumin in turmeric is between 4-5% (Bengmark et al., 2009). With that being stated, the curcumin level was calculated by taking 4% of 2 g of turmeric, thus giving the concentration of 80 mg of curcumin/kg of diet. However, the concentration of curcumin in turmeric is extremely variable, which is thought to be dependent on soil acidity and available nutrients to the plant. Research has shown that the highest concentrations of curcumin are found in pure turmeric powder (Tayyem et al., 2006). The turmeric powder fed in this experiment did not follow the average. The average curcumin concentration in our turmeric powder was only 1.25%. Most commercially available curcumin is not 100% curcumin; it is 77% curcumin, 17% DMC, and 3% BDMC (Anand et al., 2008). The curcumin was labeled as 95% curcumin, but after analysis the curcumin powder was 58% curcumin, 12% DMC, and 2% BDMC. The curcumin powder did not meet the average commercial standards for curcuminoid concentrations. The curcumin was 46.4 mg/kg of curcumin.

Previous results from Chapter III showed the addition of 2, 4, or 8 g of turmeric/kg of diet linearly increased ADG, ADFI, and G:F when compared to pigs fed a control diet (no antibiotics). Also, pigs fed turmeric in Chapter III had a

blunted response to a LPS challenge when compared to the control. However, the results in this study are not the same. When pigs were fed turmeric, there was a decrease in gain, feed intake, and feed efficiency. The response to the LPS challenge in this study was not blunted like that observed in Chapter III. The turmeric from this study and the turmeric from the Chapter III did not come from the same supplier and had different levels of curcuminoids. The turmeric from Chapter III had higher concentrations of curcuminoids than the turmeric powder in this study. Curcumin concentrations in Chapter III were 47.2, 94.4, and 188.8 mg/kg of diet for the turmeric concentrations of 2, 4, and 8 g/kg of diet, respectively. The concentration of curcumin in the turmeric fed in this study was 25 mg/kg of diet. The differences in growth performance from this experiment and Chapter III study could be due to curcuminoids and/or curcumin concentrations. The curcumin concentration in the turmeric in this study might have been too low to have an effect on growth performance and immune response.

Another possible explanation for the differences observed in this study could be the supplier. The turmeric from Chapter III was grown in Hawaii and had been refined by having the arsenic removed (personal communication). The exact location of cultivation of the turmeric in this experiment is not known. The differences in turmeric could be due to different growing environments.

Published research for feeding turmeric or curcumin to swine is limiting. When 250 mg/kg (~75 mg/kg of CUR) and 500 mg/kg (~175 mg/kg of CUR) of an herbal extract mixture (HEM) was fed to growing pigs, the ADG and ADFI was

comparable to pigs fed a subtherapeutic antibiotic (apramycin at 30 mg/kg of the diet). The pigs fed the HEM had higher ADG and ADFI than the pigs fed the negative control (no antibiotics). The HEM contained black pepper, curcuma, ginger, buckwheat, and thyme that was ground and extracted with 70% methanol. The ratio of the mixture was 10:30:35:10:15, respectively (Yan et al., 2011). Therefore, approximately one-third of the mixture was curcuma. The differences in growth performance were not due to an increase in nutrient digestibility because there were no differences observed. However, both treatments of herbal-fed pigs had higher white and red blood cell counts and % lymphocytes than the antibiotic-fed pigs after 6 weeks. The authors attribute this change in blood chemistry to the enhanced growth performance. It was stated the HEM deterred the growth of pathogenic microbes, thus creating a healthier gastrointestinal tract and healthier pigs (Yan et al., 2011). The results in this study are similar to Yan et al. (2011) results. Pigs fed curcumin had similar growth performance as pigs fed carbadox. It would have been interesting to see if there was an increase in the same blood cells as observed in Yan et al. (2011). This might have given a better picture of why the curcumin and not the turmeric increased growth performance.

Bille et al. (1985) reported antagonistic effects on growth performance for pigs fed a turmeric oleoresin. When pigs were fed 1551 mg/kg of BW/d of turmeric oleoresin, gain and feed efficiency were depressed. It was also reported as oleoresin increased the weights of the liver and thyroid increased (Bille et al., 1985). Supplementation of 2 g/kg of turmeric, in this study, decreased ADG,

ADFI, and G:F, when compared to pigs fed a control diet (no antibiotics), antibiotic diet (carbadox), and curcumin. However, pigs fed turmeric in this study only consumed 68.6 mg/kg of BW/d of turmeric. It was stated in Bille et al. (1985) that the decrease in performance could have been due to the high curcumin concentrations (271 mg/kg of BW/d) in the turmeric oleoresin or from other components in the oleoresin. In this study, the decrease in performance from consuming turmeric was not due to high concentrations of curcumin because the level of intake of curcumin was 0.86 mg/kg of BW/d. Therefore, it could be other components present in the turmeric that adversely effected feed intake.

Another study by Ilsley et al. (2005) also reported no effect on growth performance in nursery pigs fed 200 mg/kg of curcumin when compared to a control diet containing no antibiotics. However, this is not in agreement with the current study. The addition of 46.4 mg/kg of curcumin to the diet did increase growth performance in nursery pigs when compared to a control diet with no antibiotics. The difference between our study and Ilsley et al. (2005) could be the curcumin source or curcumin extraction method.

Weaning and an immune challenge are stressful events for nursery pigs. Research has reported that curcumin/turmeric helps alleviate problems that occur during stressful periods. Another stress for nursery pigs is traveling stress. Wei et al. (2010) reported traveling pressure was lessened when pigs were fed 8 mg/kg of curcumin for 21 days before travel. Curcumin reduced cortisol and nitric oxide production. It also reduced the enzymatic activity of total nitric oxide

synthase (NOS), constitutive NOS (cNOS), and inducible (iNOS). Expression of cNOS was reduced with supplementation of curcumin (Wei et al., 2010). Post-weaning lag is the most stressful event for a pig. In fact, cortisol levels are elevated after weaning (van der Meulen et al., 2010; Wijtten et al., 2011), which can produce detrimental effects in the gastrointestinal tract of the nursery pigs (van der Meulen et al., 2010). The pigs fed curcumin in this study may have similar results as Wei et al. (2010) where cortisol levels were reduced, thus leading to a healthier digestive tract and improved growth performance.

Over 20 years ago, when compared to a diet containing no antibiotics, subtherapeutic antibiotics improved ADG by 13.2%-16.9% and feed efficiency by 4.7%-7.0% in nursery pigs in a research location. The improvement in growth performance was even greater in a commercial setting and/or in a “dirty” environment (Cromwell, 2001). Current research suggests subtherapeutic antibiotics do not have the improvement they use to have due to changes in the swine industry, such as improved biosecurity and animal husbandry (Jacela et al., 2009). Jacela et al. (2009) reported subtherapeutic antibiotics in nursery diets in a commercial setting have an improvement of 5.2% for ADG and 1.4% for feed efficiency, when compared to pigs fed a non-antibiotic diet. This current study agrees with Jacela et al. (2009). Pigs fed the antibiotic diet had a 4.6% and 4.1% improvement for ADG and G:F, respectively, when compared to pigs fed the control (no antibiotic) diet.

To study the effects of curcumin on the immune response a LPS challenge was performed. Lipopolysaccharide is a cell wall component located

on the outer membrane of a bacterium (Mandali et al., 2002). Some symptoms of LPS after administration include: anorexia, decreased activity, fever, and somnolescence or drowsiness (Moya et al., 2009). The *E. coli* O111:B4 LPS injected in this study has proven to elicit an immune response in nursery pigs (Mandali et al., 2000; Mandali et al., 2002; Smith, 2006; Bible, 2009; Williams et al., 2009).

An indicatory of an immune response is fever (Van Gucht et al., 2004). A fever and other indicators of inflammation can be activated by LPS. The LPS activates the release of pro-inflammatory cytokines from neutrophils and macrophages (Moya et al., 2006). It can trigger the innate immune system just like a live bacterium (Mandali et al., 2002). Inflammation occurs in a series of steps. First, the LPS must be transported to the cluster of differentiation 14 (CD14). The transporter protein is the soluble LPS binding protein (LBP). Then, the LPS binds to the CD14, which moves the LPS to the TLR4/MD-2 (toll-like receptor 4/myeloid differentiation protein) complex. The binding to this complex initiates a downstream signaling, through NF-κB, to activate pro-inflammatory cytokines, such as TNF-α (Lu et al., 2008; Bryant et al., 2010). Finally, the pro-inflammatory cytokines activate metabolism of arachidonic acid, which produces COX-2. Prostaglandin E2 (PGE2) is produced from COX activation and PGE2 induces thermal activation or a fever in the hypothalamus (Ogoina, 2011).

The TNF-α response in this study coincides with other reported research. Research has demonstrated an *E. coli* LPS challenge increases the pro-inflammatory cytokines interleukin-6 (IL-6), interleukin-1β (IL-1β), and TNF-α in a

time-dependent manner. The peak hours for IL-6, IL-1β, and TNF-α were 2.5 h, 3 h, and 1 h post-LPS, respectively, in pigs injected with *E. coli* O111:B4 at 25 µg/kg of BW (Williams et al., 2009). Webel et al. (1997) reported after 2 hours of an intraperitoneal injection of 5 µL/kg of body weight of LPS *E. coli* K-235, TNF-α was elevated 10-fold and interleukin-6 (IL-6) was elevated 200-fold by hour 4 of the challenge. Another low-dose LPS challenge reported peak TNF-α levels at 2 h PI (Moya et al., 2006). The peak TNF-α concentrations observed for our study was at h 3 PI.

Curcumin has shown in previous studies to attenuate a LPS response by inhibiting or decreasing the pro-inflammatory cytokines (Sompamit et al., 2009). A possible mechanism for inhibiting the inflammatory response is the ability of curcumin to bind to the myeloid differentiation protein 2 (MD-2). The MD-2 protein is involved in the TLR4/MD-2 complex that binds to CD14, and CD14 binds LBP, which binds LPS (Gradisar et al., 2007). Therefore, less LPS binding causes a decrease in pro-inflammatory cytokine production and less inflammation. Research has also shown that curcumin has the capability to inhibit the binding of NF-κB to DNA in mice HK-2 (renal) cell infected with LPS (Zhong et al., 2011). However, it might not be curcumin (CUR) alone that helps inhibit the immune response. The other curcuminoids, demethoxycurcumin, and bisdemethoxycurcumin, could have some effect on the innate immune response. In fact, Zhang et al. (2008) reported the potency of curcuminoids for decreasing nitric oxide and TNF-α was DMC > BDMC > CUR in rat microglia infected with LPS. The exact mechanism of curcumin is not completely understood.

The current study is similar to other research reported with curcumin reducing TNF-α. Lantz et al. (2005) reported that curcumin and an organic extract of turmeric were capable of inhibiting TNF-α and PGE2. Liu et al. (2013b) reported a reduction in TNF-α in pigs experimentally infected with *E. coli* that were fed 10 mg/kg of turmeric oleoresin compared to the control pigs. Another study by Liu et al. (2013a) also reported similar results in pigs infected with PRRS virus consuming 10 mg/kg of turmeric oleoresin. Pigs fed curcumin in this study had lower a TNF-α concentration at h 3 PI when compared to pigs fed a control, antibiotic, or turmeric diet. The pigs fed turmeric in this study did not have the decrease in TNF-α as observed in previous studies. Again, the differences observed between the CUR and TUM diets could be due to curcumin concentrations where TUM diet had a lower curcumin concentration compared to CUR diet.

Pigs in this experiment lost body weight and were less active after injection of LPS. These results are similar to other research with pigs and a LPS challenge. Moya et al. (2006) reported a decrease in behavior in a low-dose LPS challenge where LPS-challenged pigs spent less time alert during resting. The activity score and BW loss are more than likely related. If the pigs are not active, then their feed consumption is decreased. A reduction in feed intake was reported in pigs during a LPS challenge by Wright et al. (2000). Body weight would be lost due to a reduction in feed intake. Pigs fed curcumin did not lose as much body mass as pigs fed turmeric or antibiotic in the current experiment.

Blood urea nitrogen, glucose, total protein, and triglycerides were measured during the LPS challenge. Urea nitrogen is an indicator of protein degradation in starving or food-deprived animals. Research has reported an increase in plasma urea nitrogen (PUN) during a LPS challenge. The inflammatory cytokine TNF-α can also increase muscle catabolism (Webel et al., 1997). Similar results were reported in this study. Pigs had increasing levels of BUN after an increase in TNF-α as indicated by the body weight loss. The pigs fed curcumin had the lowest BUN levels, which could, in part, be due to the decreased production of TNF-α. Pigs fed turmeric had the highest concentrations of BUN and also had the highest levels of TNF-α.

A decrease in glucose and an increase in triglycerides were observed in the current experiment, which is similar to results reported by Webel et al. (1997). Most of the changes in these blood analytes are due to feed deprivation and inflammation (Webel et al., 1997). If the pigs are less active and have a fever, they are less likely to eat. Little to no feed intake leads to temporary starvation, thus a reduction in glucose levels. If glucose (energy) levels decrease in the blood, the body will produce energy from other sources, such as fat (triglycerides) and protein (BUN). Thus, the increase in triglycerides and BUN could be due to the decrease in glucose. Pigs fed curcumin had lower levels of BUN and triglycerides and higher glucose levels. Curcumin has been shown to regulate glucose in diabetes (Bengmark et al., 2009); therefore, curcumin fed in this study could have regulated glucose levels resulting in higher blood glucose and lower BUN and triglycerides.

The acute phase protein, CRP, is activated in the liver by TNF-α (Liu et al., 2013b). C-reactive protein has a half-life of approximately 12 hours; therefore, it dissipates rather rapidly after the acute phase protein response. The peak of CRP is dependent on several actions, which are: production and liberation of TNF-α, interaction of TNF-α with hepatocytes, synthesis of CRP by the liver, and the buildup of CRP in the plasma part (Moya et al., 2006). As stated earlier, TNF-α increases protein catabolism. The amino acids released during this catabolism are believed to aide in synthesis of acute phase protein by providing fuel for the hepatocytes. The acute phase proteins may increase by 25% or more after an infection (Webel et al., 1997).

Moya et al. (2006) reported peak TNF-α concentrations at h 2 PI with corresponding peak CRP concentrations at h 12 PI. In the current study, the peak TNF-α concentrations were 3 hours after injection and peak CRP levels at 24 h PI. Therefore, it is possible that, in this experiment, the peak CRP levels were missed due to the short half-life of CRP. The peak CRP levels might have increased between 12 and 24 h PI. However, Williams et al. (2009) reported CRP levels started increasing at h 6 PI and continued to increase to h 24 PI. These results do concur with this experiment where CRP levels were the highest at 24 PI. The CNT diet had lower levels of CRP at h 24 PI compared to the AB, TUM, and CUR diets. The response of pigs fed CNT could be slower than the pigs fed the other diets, but the exact reasoning behind the lower CRP concentrations is not completely understood.

A cost analysis was calculated for this experiment. All cost/pig and cost/gain/pig are in Table IV.9. For d 0-21, TUM diet was the most expensive diet on a cost/kg, followed by the CUR and AB, and finally the CNT diet being the cheapest. The CNT diet was the cheapest on a cost/pig basis and the AB diet was the most expensive. The TUM and CUR diets were intermediate for cost/pig. However, on a cost/gain/pig basis the TUM diet was the most expensive and the other diets were very similar in cost. For d 0-42, the diet cost on a per kg basis was similar to the diet cost for d 0-21, where the diet cost from cheapest to most expensive was CNT, AB, CUR, and TUM. The AB diet was the most expensive on a cost/pig basis and the CNT diet was the cheapest. The TUM and CUR diets were intermediate in cost. On a cost/gain/pig basis, TUM cost the most and the other diets were similar in cost. Even though the CNT diet was cheaper by $0.03 on a cost/gain/pig basis, it should be stated that the pigs fed the CNT were approximately one kg lighter than pigs fed AB and CUR. This lighter BW will result in more days in the finisher, thus a greater overall cost/pig. In the end, the AB and CUR diets were similar on a cost/gain/pig basis.

CONCLUSION

In conclusion, turmeric supplementation in this study had negative implications on growth performance and immune response in nursery pigs, possibly due to the lower curcumin concentrations and/or some other negative components. However, pigs fed curcumin had similar growth performance to pigs fed carbadox. Curcumin also decreased the response to an *E. coli* lipopolysaccharide challenge. Therefore, curcumin has the possibility to replace

carbadox in nursery diets to maintain growth performance and mitigates the immune response to a Gram-negative bacterial infection. Further research should be conducted to optimize the level of curcumin to have maximum growth response and immunomodulation in nursery pigs.

Table IV.1 Diet composition of phase 1 diets

	% in diet			
Ingredients	**CNT[a]**	**AB[a]**	**TUM[a]**	**CUR[a]**
Corn	32.01	30.99	31.20	32.00
Soybean meal, dehulled	15.00	15.00	15.00	15.00
Whey, dried	25.00	25.00	25.00	25.00
Lactose	7.00	7.00	7.00	7.00
Plasma, spray-dried	6.00	6.00	6.00	6.00
Fishmeal, menhaden	6.00	6.00	6.00	6.00
Soy protein concentrate	2.21	2.21	2.21	2.21
Soybean oil	4.00	4.00	4.00	4.00
L-lysine HCl	0.20	0.20	0.20	0.20
DL-methionine	0.18	0.19	0.19	0.18
L-threonine	0.06	0.07	0.06	0.06
Dicalcium phosphate	0.71	0.71	0.71	0.71
Limestone	0.45	0.45	0.45	0.45
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28
Vitamin premix[b]	0.25	0.25	0.25	0.25
Trace mineral premix[c]	0.15	0.15	0.15	0.15
Mecadox[d]	-----	1.00	-----	-----
Turmeric powder	-----	-----	0.20	-----
Curcumin powder	-----	-----	-----	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1597	1582	1594	1597
Crude protein, %	23.00	23.93	22.99	23.00
SID Lysine, %	1.56	1.56	1.56	1.56
Calcium, %	0.90	0.90	0.90	0.90
Available phosphorus, %	0.60	0.60	0.60	0.60

[a]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided on per kg diet: 11023 IU of vitamin A as vitamin A acetate, 1653 IU of vitamin D_3, 44.1 IU of vitamin E as vitamin E acetate, 4.41 mg of vitamin K as menadione bisulfate, 0.0441 mg of vitamin B_{12}, 9.92 mg of riboflavin; 33.1 mg of pantothenic acid as d-Cal pantothenic acid, 55.1 mg of niacin as nicotinic acid.
[c]Mineral mix provided on per kg basis: 165 mg of zinc as zinc sulfate, 165 mg of iron as iron sulfate, 39.7 mg of manganese as manganese oxide, 16.5 mg of copper as copper sulfate, 298 mg of iodine as calcium iodate, 298 mg of selenium as sodium selenite.

Table IV.2 Diet composition of phase 2 diets

	% in diet			
Ingredients	**CNT[a]**	**AB[a]**	**TUM[a]**	**CUR[a]**
Corn	38.14	37.06	37.22	38.13
Soybean meal, dehulled	20.00	20.00	20.00	20.00
Whey, dried	25.00	25.00	25.00	25.00
Plasma, spray-dried	2.50	2.50	2.50	2.50
Blood cells, spray-dried	1.25	1.25	1.25	1.25
Fishmeal, menhaden	4.00	4.00	4.00	4.00
Soy protein concentrate	2.04	2.12	2.05	2.04
Soybean oil	4.00	4.00	4.00	4.00
L-lysine HCl	0.22	0.22	0.22	0.22
DL-methionine	0.21	0.21	0.21	0.21
L-threonine	0.09	0.09	0.09	0.09
Dicalcium phosphate	0.93	0.93	0.93	0.93
Limestone	0.44	0.44	0.44	0.44
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28
Vitamin premix[b]	0.25	0.25	0.25	0.25
Trace mineral premix[c]	0.15	0.15	0.15	0.15
Mecadox[d]	-----	1.00	-----	-----
Turmeric powder	-----	-----	0.20	-----
Curcumin powder	-----	-----	-----	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1589	1573	1586	1589
Crude protein, %	22.98	22.95	22.98	22.98
SID Lysine, %	1.51	1.51	1.51	1.51
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.55	0.55	0.55	0.55

[a]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided on per kg diet: 11023 IU of vitamin A as vitamin A acetate, 1653 IU of vitamin D_3, 44.1 IU of vitamin E as vitamin E acetate, 4.41 mg of vitamin K as menadione bisulfate, 0.0441 mg of vitamin B_{12}, 9.92 mg of riboflavin; 33.1 mg of pantothenic acid as d-Cal pantothenic acid, 55.1 mg of niacin as nicotinic acid.
[c]Mineral mix provided on per kg basis: 165 mg of zinc as zinc sulfate, 165 mg of iron as iron sulfate, 39.7 mg of manganese as manganese oxide, 16.5 mg of copper as copper sulfate, 298 mg of iodine as calcium iodate, 298 mg of selenium as sodium selenite.

Table IV.3 Diet composition of phase 3 diets

	% in diet			
Ingredients	**CNT[a]**	**AB[a]**	**TUM[a]**	**CUR[a]**
Corn	53.77	52.77	52.98	53.77
Soybean meal, dehulled	26.12	26.12	26.12	26.12
Whey, dried	10.00	10.00	10.00	10.00
Fishmeal, menhaden	2.00	2.00	2.00	2.00
Blood cells, spray-dried	1.25	1.25	1.25	1.25
Soybean oil	3.00	3.00	3.00	3.00
L-lysine HCl	0.27	0.28	0.28	0.27
DL-methionine	0.17	0.17	0.17	0.17
L-threonine	0.12	0.12	0.12	0.12
Dicalcium phosphate	1.39	1.39	1.39	1.39
Limestone	0.72	0.72	0.72	0.72
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28
Vitamin premix[b]	0.25	0.25	0.25	0.25
Trace mineral premix[c]	0.15	0.15	0.15	0.15
Mecadox[d]	-----	1.00	-----	-----
Turmeric powder	-----	------	0.20	-----
Curcumin powder	-----	-----	-----	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1563	1547	1560	1563
Crude protein, %	20.93	20.85	20.91	20.93
SID Lysine, %	1.31	1.31	1.31	1.31
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.45	0.45	0.45	0.45

[a]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided on per kg diet: 11023 IU of vitamin A as vitamin A acetate, 1653 IU of vitamin D_3, 44.1 IU of vitamin E as vitamin E acetate, 4.41 mg of vitamin K as menadione bisulfate, 0.0441 mg of vitamin B_{12}, 9.92 mg of riboflavin; 33.1 mg of pantothenic acid as d-Cal pantothenic acid, 55.1 mg of niacin as nicotinic acid.
[c]Mineral mix provided on per kg basis: 165 mg of zinc as zinc sulfate, 165 mg of iron as iron sulfate, 39.7 mg of manganese as manganese oxide, 16.5 mg of copper as copper sulfate, 298 mg of iodine as calcium iodate, 298 mg of selenium as sodium selenite.

Table IV.4 Diet composition of phase 4 diets

	% in diet			
Ingredients	**CNT[a]**	**AB[a]**	**TUM[a]**	**CUR[a]**
Corn	59.02	58.01	58.22	59.00
Soybean meal, dehulled	34.31	34.31	34.31	34.31
Soybean oil	3.00	3.00	3.00	3.00
L-lysine HCl	0.25	0.25	0.25	0.25
DL-methionine	0.11	0.11	0.11	0.11
L-threonine	0.08	0.09	0.08	0.08
Dicalcium phosphate	1.58	1.58	1.58	1.58
Limestone	0.75	0.75	0.75	0.75
Salt	0.50	0.50	0.50	0.50
Vitamin premix[b]	0.25	0.25	0.25	0.25
Trace mineral premix[c]	0.15	0.15	0.15	0.15
Mecadox[d]	-----	1.00	-----	-----
Turmeric powder	-----	-----	0.20	-----
Curcumin powder	-----	-----	-----	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1568	1552	1645	1648
Crude protein, %	21.56	21.48	21.54	21.56
SID Lysine, %	1.25	1.25	1.25	1.25
Calcium, %	0.75	0.75	0.75	0.75
Available phosphorus, %	0.37	0.37	0.37	0.37

[a]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided on per kg diet: 11023 IU of vitamin A as vitamin A acetate, 1653 IU of vitamin D_3, 44.1 IU of vitamin E as vitamin E acetate, 4.41 mg of vitamin K as menadione bisulfate, 0.0441 mg of vitamin B_{12}, 9.92 mg of riboflavin; 33.1 mg of pantothenic acid as d-Cal pantothenic acid, 55.1 mg of niacin as nicotinic acid.
[c]Mineral mix provided on per kg basis: 165 mg of zinc as zinc sulfate, 165 mg of iron as iron sulfate, 39.7 mg of manganese as manganese oxide, 16.5 mg of copper as copper sulfate, 298 mg of iodine as calcium iodate, 298 mg of selenium as sodium selenite.

Table IV.5. Calculated curcuminoid concentrations of curcumin and turmeric powder fed to nursery pigs

	Powder (%)			Curcuminoid (mg/kg of diet)		
Treatment	CUR[a]	DMC[b]	BDMC[c]	CUR[a]	DMC[b]	BDMC[c]
Turmeric[d]	1.25	0.45	0.34	25.0	9.0	6.8
Curcumin[e]	57.99	12.02	2.03	46.4	9.6	1.6

[a]CUR = curcumin.
[b]DMC = demethoxycurcumin.
[c]BDMC = bisdemethoxycurcumin.
[d]Turmeric = 2 g of turmeric/kg of diet; formulated concentration.
[e]Curcumin = 80 mg of curcumin/kg of diet; formulated concentration.

Table IV.6. Effects of feeding of curcumin powder vs. carbadox on growth performance of nursery pigs[a]

	Treatments[b]					
	CNT	**AB**	**TUM**	**CUR**	**SE**	**P =**
BW, kg						
d 0	5.8	5.8	5.8	5.8	0.02	0.82
d 7	7.0	7.2	7.1	8.3	0.08	0.45
d 14	8.6^{x}	9.0^{y}	8.7^{x}	$8.8^{x,y}$	0.11	0.04
d 21	$12.5^{x,z}$	13.2^{y}	12.4^{x}	$13.0^{y,z}$	0.19	0.02
d 42	23.5^{x}	24.5^{y}	23.0^{x}	24.2^{y}	0.23	0.0007
ADG, g						
d 0-7	195	215	200	214	11.6	0.53
d 7-14	241^{x}	289^{y}	250^{x}	253^{x}	9.2	0.007
d 14-21	$403^{x,y}$	$424^{x,y}$	391^{y}	438^{x}	13.9	0.10
d 0-21	$294^{x,z}$	324^{y}	293^{x}	$317^{y,z}$	8.0	0.02
d 21-42	$603^{x,y}$	616^{y}	580^{x}	616^{y}	10.9	0.10
d 0-42	432^{x}	456^{y}	422^{x}	450^{y}	5.4	0.0008
ADFI, g						
d 0-7	258	275	260	271	5.8	0.12
d 7-14	394^{x}	424^{y}	386^{x}	395^{x}	9.8	0.06
d 14-21	665	681	632	663	21.0	0.43
d 0-21	466	489	453	468	10.4	0.15
d 21-42	1074	1070	1023	1061	30.5	0.67
d 0-42	734	745	710	731	16.4	0.53
G:F						
d 0-7	0.719	0.749	0.717	0.736	0.0374	0.92
d 7-14	0.595	0.675	0.639	0.627	0.0223	0.11
d 14-21	0.610	0.625	0.621	0.663	0.0171	0.18
d 0-21	0.633	0.662	0.644	0.678	0.0133	0.11
d 21-42	0.564	0.578	0.571	0.585	0.0163	0.82
d 0-42	0.591	0.615	0.597	0.618	0.0112	0.27

[a]Least squares means for 8 pens/treatment.
[b]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.
[x,y,z]Means with different superscripts in the same row differ.

Table IV.7. Effects of feeding curcumin vs. carbadox on BW loss, rectal temperature, and activity score of nursery pigs during a LPS[a] challenge

	Treatments[b]					P =		
	CNT	AB	TUM	CUR	SE	Trt	Hr	Trt x Hr
Rectal temperature[c], °C						0.68	<0.0001	0.39
h 0	39.5	39.7	39.8	39.9	0.18	0.47		
h 3	41.4	41.5	41.2	41.7	0.18	0.39		
h 6	41.1	40.9	41.1	40.7	0.18	0.29		
h 12	40.4	40.8	40.4	40.5	0.18	0.37		
h 24	39.5	39.7	39.5	39.7	0.18	0.72		
Activity score[d]						0.41	<0.0001	0.21
h 0	5.0	5.0	5.0	5.0	0.25	1.00		
h 3	3.0	2.7	3.0	3.3	0.25	0.34		
h 6	2.3	1.7	1.7	2.0	0.25	0.21		
h 12	3.7^{x}	$3.3^{x,y}$	$3.0^{x,y}$	2.7^{y}	0.25	0.05		
h 24	5.0	4.7	5.0	5.0	0.25	0.73		
% BW of h 0[c]								
h 3	97.6^{x}	95.3^{y}	95.2^{y}	97.0^{x}	0.52	0.01		
h 6	96.5^{x}	94.4^{y}	94.3^{y}	96.9^{x}	0.65	0.02		
h 12	95.8^{x}	94.3^{x}	94.9^{x}	97.9^{y}	0.64	0.007		
h 24	98.5	96.0	97.1	99.5	1.30	0.13		

[a]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[b]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.
[c]Least squares means for 6 pens/treatment.
[d]Least squares means for 3 pens/treatment; Activity score – 1 = inactive; 3 = moderately active; 5 = highly active.
[x,y,z]Means with different superscripts in the same row differ.

Table IV.8. Effects of feeding curcumin vs. carbadox on blood analytes of nursery pigs during a LPS[a] challenge[b]

	Treatments[c]					P =		
	CNT	AB	TUM	CUR	SE	Trt	Hr	Trt x Hr
TNF-α[d], pg/mL						0.003	<0.0001	0.001
h 0	110	138	86	104	330	0.99		
h 3	5065[x]	3791[y]	5308[x]	2798[z]	330	<0.0001		
h 6	1244	1197	1326	965	330	0.85		
h 24	117	111	171	110	330	0.99		
CRP[e], mg/L						0.06	<0.0001	0.52
h 0	0.44	0.78	0.89	1.24	0.34	0.31		
h 3	0.54	0.86	0.96	1.14	0.34	0.56		
h 6	0.93	1.32	1.40	1.70	0.34	0.35		
h 24	2.11[x]	3.57[y]	3.18[y]	3.37[y]	0.34	0.004		
BUN[f], mg/dL						0.20	<0.0001	0.85
h 0	5.8	5.3	6.8	5.7	1.1	0.77		
h 3	5.9	7.3	6.7	5.9	1.1	0.74		
h 6	7.6	9.0	9.9	7.3	1.1	0.26		
h 24	10.7	10.8	12.7	9.1	1.1	0.13		
Glucose, mg/dL						0.18	<0.0001	0.12
h 0	99.1	109	103	111	6.1	0.52		
h 3	91.6[x,z]	71.7[y]	77.7[x,y]	97.4[z]	6.1	0.009		
h 6	76.9	77.4	73.5	77.6	6.1	0.96		
h 24	87.1	96.9	102	103	6.1	0.22		
Total protein, g/dL						0.41	0.007	0.74
h 0	4.4	4.5	4.4	4.8	2.5	0.54		
h 3	4.2	3.8	4.0	4.4	2.5	0.43		
h 6	4.2	3.9	4.2	3.7	2.5	0.53		
h 24	4.5	4.2	4.5	4.6	2.5	0.69		
Triglyceride, mg/L						0.64	0.04	0.65
h 0	25.6	24.4	31.5	31.8	7.4	0.84		
h 3	33.4	33.3	39.3	36.9	7.4	0.92		
h 6	22.6	32.9	31.7	35.5	7.4	0.63		
h 24	37.1	46.4	49.7	28.2	7.4	0.17		

[a]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[b]Least squares means for 6 pens/treatment.
[c]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.
[d]TNF-α = tumor necrosis factor-α.
[e]CRP = C-reactive protein.
[f]BUN = blood urea nitrogen.
[x,y,z]Means with different superscripts in the same row differ.

Table IV.9. Effects of curcumin vs. carbadox on cost/pig and cost/gain/pig of nursery pigs[a]

	Treatments			
	CNT[b]	**AB[b]**	**TUM[b]**	**CUR[b]**
D 0-7				
cost, $/kg	1.24	1.28	1.31	1.29
FI, kg[c]	1.81	1.93	1.82	1.90
cost/pig, $/kg	2.25	2.46	2.39	2.44
Gn[4], kg	1.37	1.51	1.40	1.50
cost/gn, $/gn/pig	1.65	1.64	1.70	1.63
D 7-14				
cost, $/kg	1.02	1.06	1.09	1.07
FI, kg[c]	2.76	2.97	2.70	2.77
cost/pig, $/kg	2.82	3.14	2.94	2.95
Gn[4], kg	1.69	2.02	1.75	1.77
cost/gn, $/gn/pig	1.67	1.55	1.68	1.67
D 14-21				
cost, $/kg	0.67	0.71	0.74	0.72
FI, kg[c]	4.66	4.77	4.42	4.64
cost/pig, $/kg	3.13	3.37	3.27	3.33
Gn[4], kg	2.82	2.97	2.74	3.07
cost/gn, $/gn/pig	1.11	1.14	1.19	1.09
D 0-21				
cost, $/kg	0.89	0.93	0.96	0.94
FI, kg[c]	9.22	9.66	8.95	9.30
cost/pig, $/kg	8.20	8.97	8.60	8.72
Gn[4], kg	6.17	6.80	6.15	6.66
cost/gn, $/gn/pig	1.33	1.32	1.40	1.31
D 21-42				
cost, $/kg	0.50	0.54	0.57	0.55
FI, kg[c]	22.6	22.5	21.5	22.3
cost/pig, $/kg	11.32	12.06	12.21	12.17
Gn[4], kg	12.7	12.9	12.2	12.9
cost/gn, $/gn/pig	0.89	0.93	1.00	0.94
D 0-42				
cost, $/kg	0.61	0.65	0.68	0.66
FI, kg[c]	31.8	32.1	30.4	31.6
cost/pig, $/kg	19.52	21.03	20.81	20.90
Gn[4], kg	18.1	19.2	17.2	18.9
cost/gn, $/gn/pig	1.08	1.10	1.17	1.11

[a]cost = U.S. dollars

[b]CNT = control diet; AB = control diet + 55 mg/kg carbadox; TUM = control diet + 2 g/kg turmeric powder; CUR = control diet + 80 mg/kg curcumin powder.

[c]FI = total feed intake.

[d]Gn = total gain.

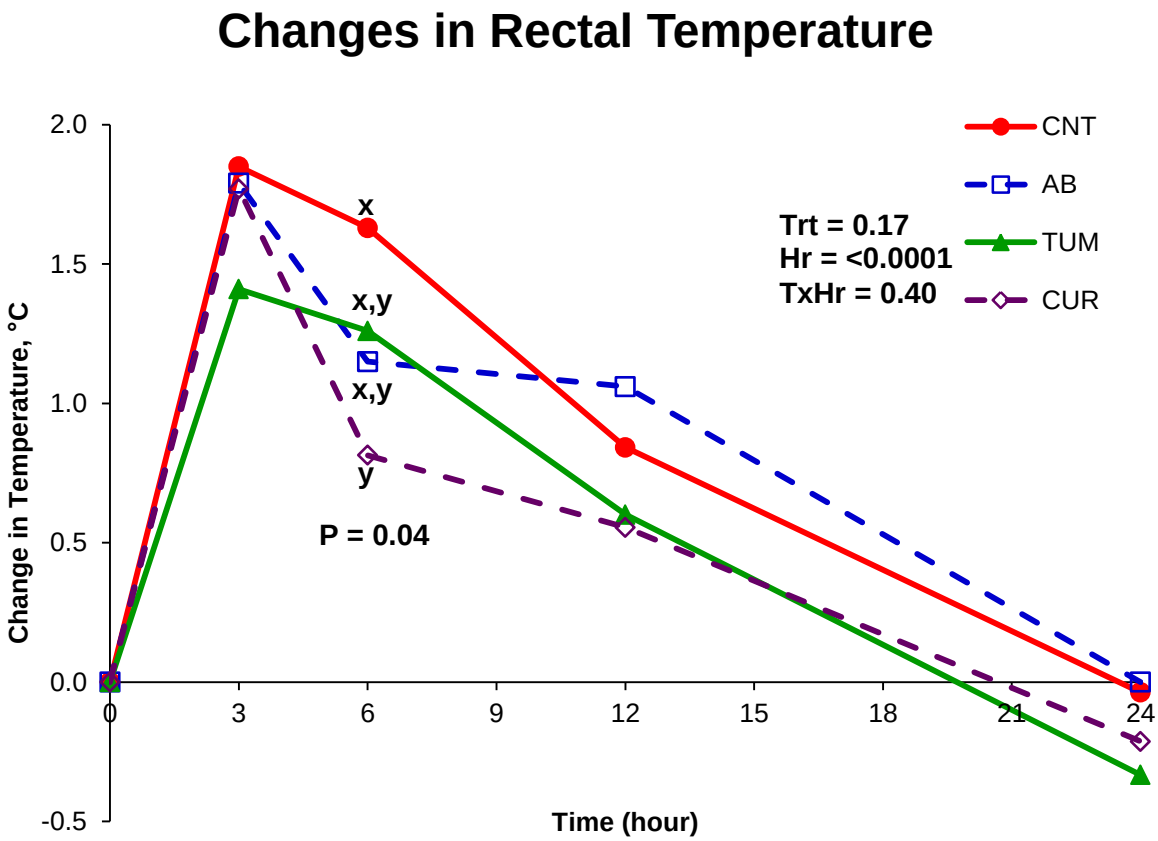


Figure IV.1. Effects of curcumin vs. carbadox on changes in rectal temperature of nursery pigs during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no antibiotic; □ – antibiotic, 55 mg/kg of carbadox; ▲ – 2 g/kg of turmeric powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

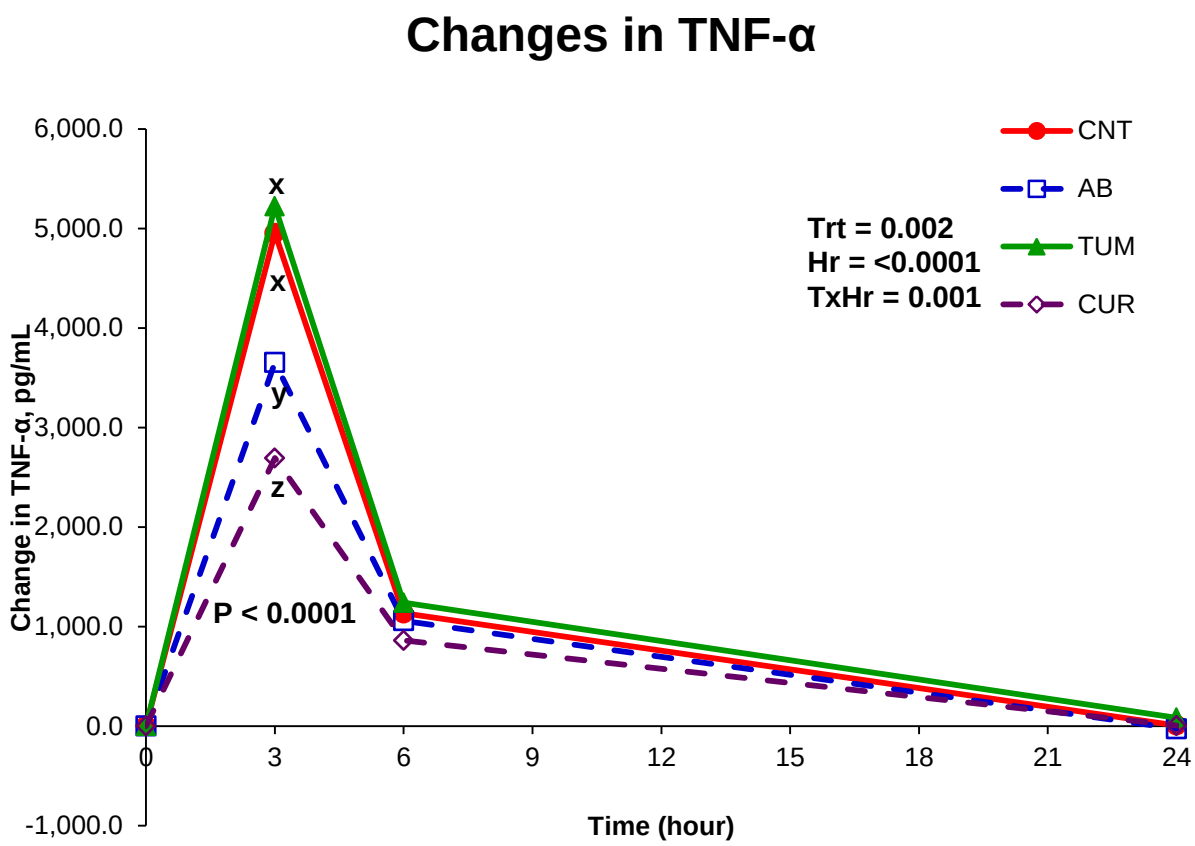


Figure IV.2. Effects of curcumin vs. carbadox on changes in serum tumor necrosis factor-α (TNF-α) of nursery pigs during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no antibiotic; □ – antibiotic, 55 mg/kg of carbadox; ▲ – 2 g/kg of turmeric powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

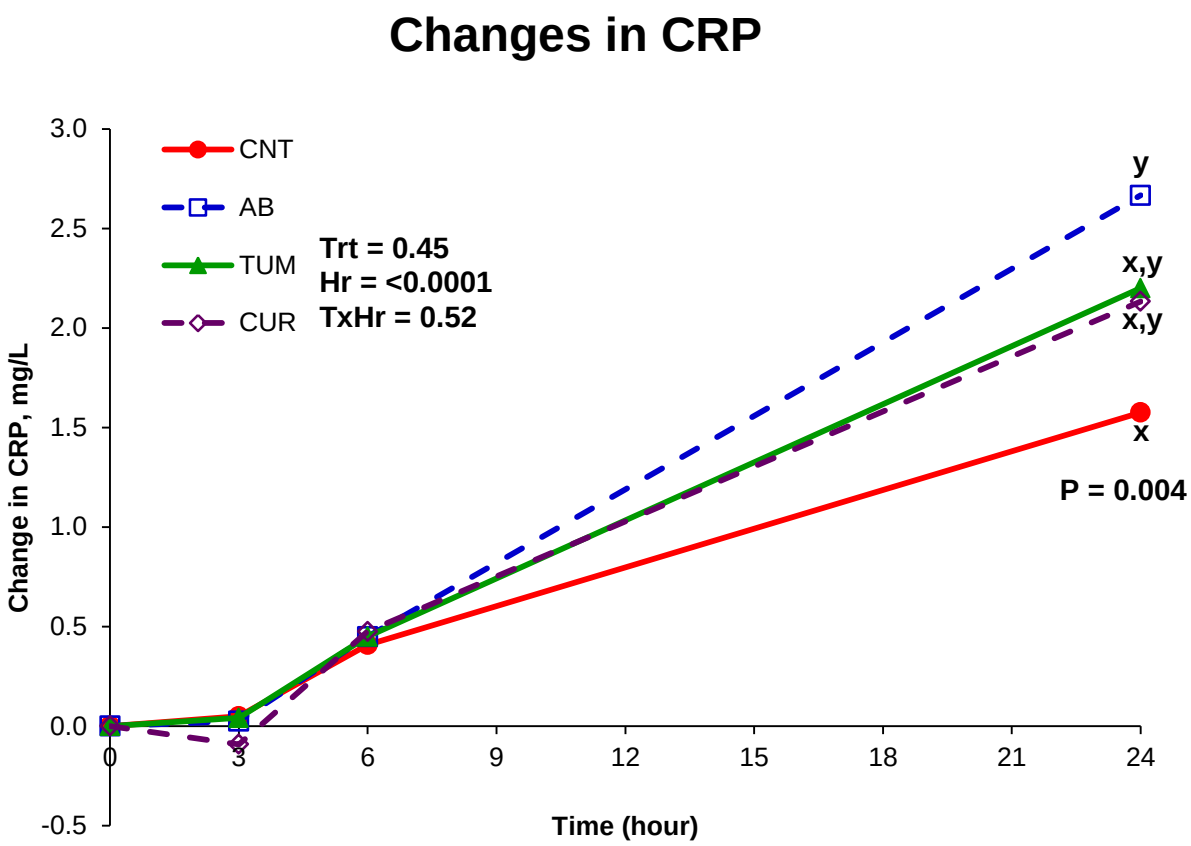


Figure IV.3. Effects of curcumin vs. carbadox on changes in serum C-reactive protein (CRP) of nursery pigs during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no antibiotic; □ – antibiotic, 55 mg/kg of carbadox; ▲ – 2 g/kg of turmeric powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

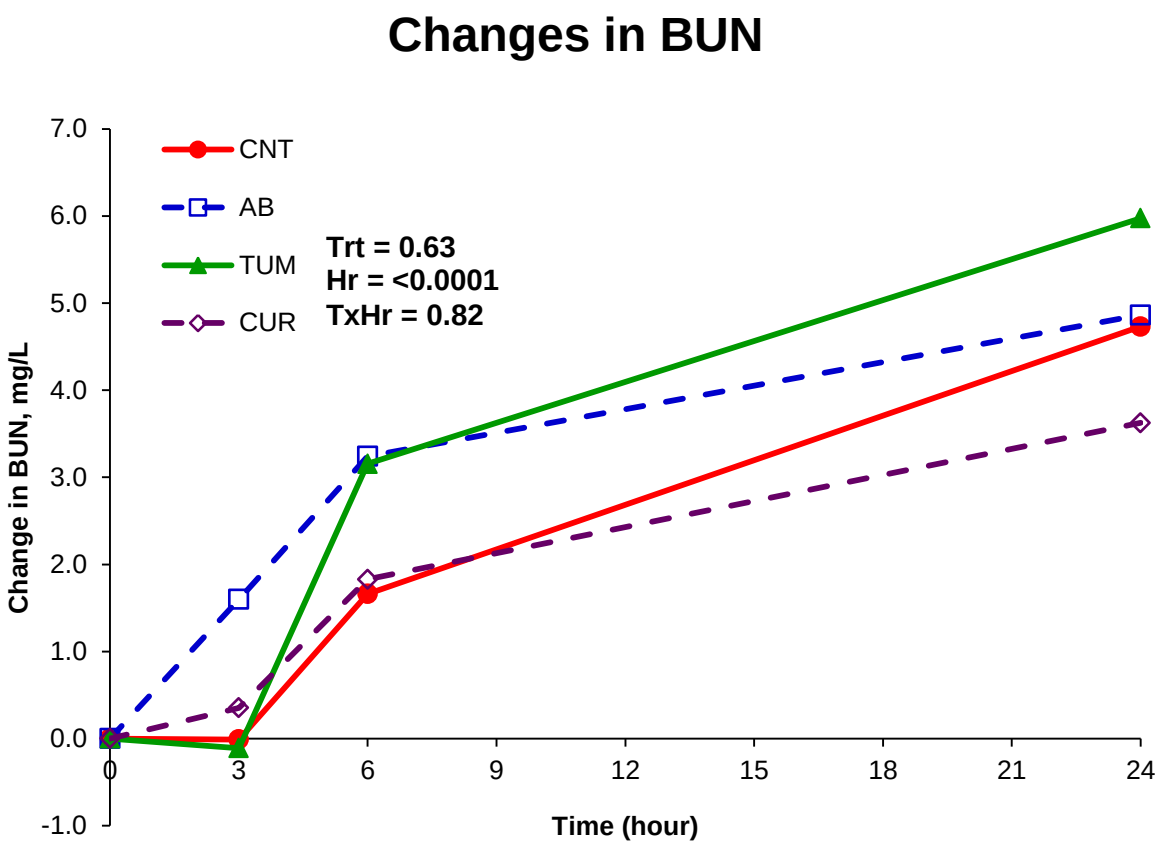


Figure IV.4. Effects of curcumin vs. carbadox on changes in serum blood urea nitrogen (BUN) of nursery pigs during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no antibiotic; □ – antibiotic, 55 mg/kg of carbadox; ▲ – 2 g/kg of turmeric powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

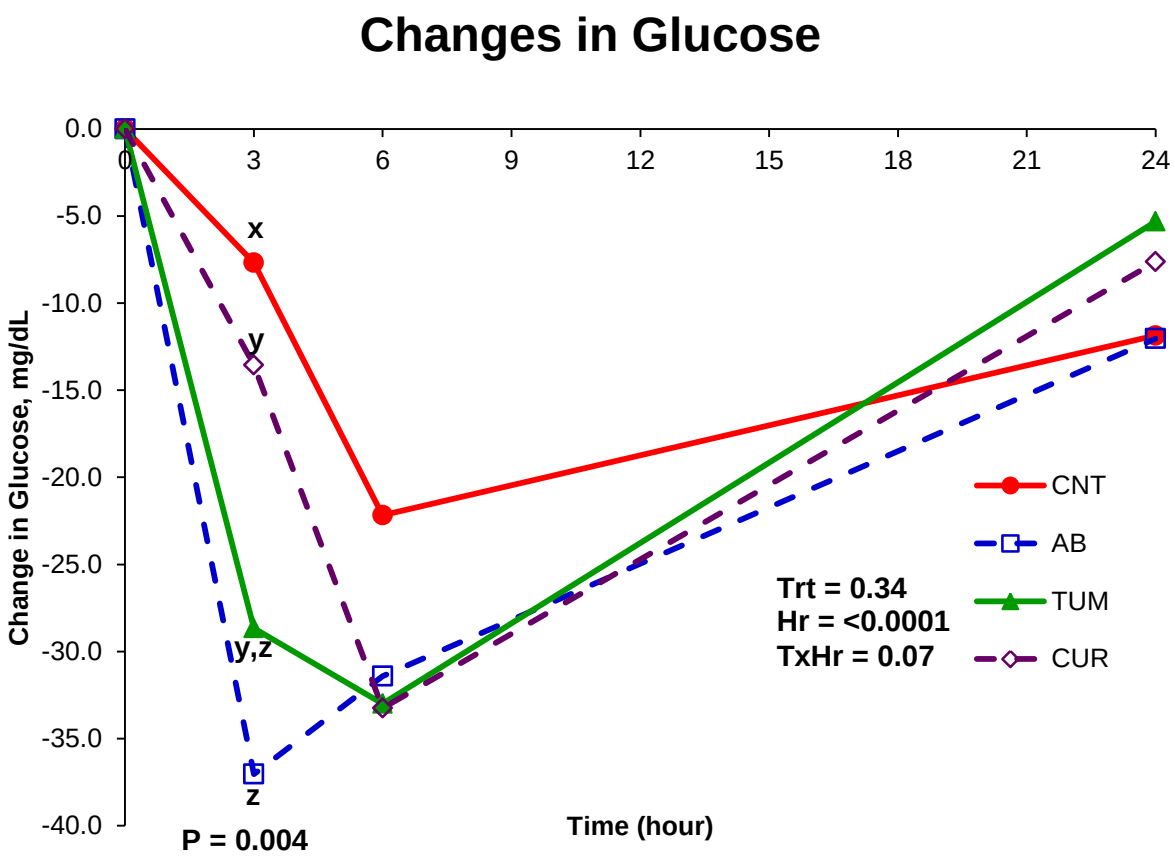


Figure IV.5. Effects of curcumin vs. carbadox on changes in serum glucose of nursery pigs during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no antibiotic; □ – antibiotic, 55 mg/kg of carbadox; ▲ – 2 g/kg of turmeric powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

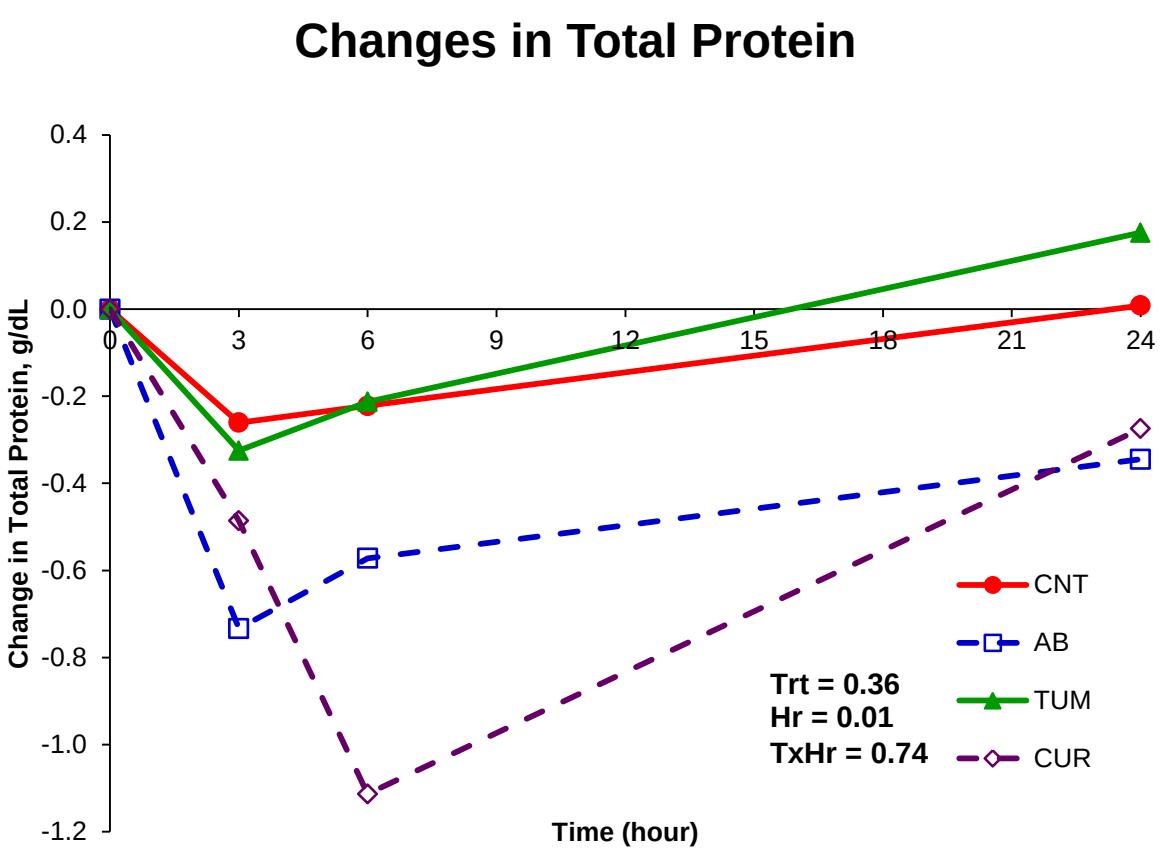


Figure IV.6. Effects of curcumin vs. carbadox on changes in serum total protein of nursery pigs during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no antibiotic; □ – antibiotic, 55 mg/kg of carbadox; ▲ – 2 g/kg of turmeric powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

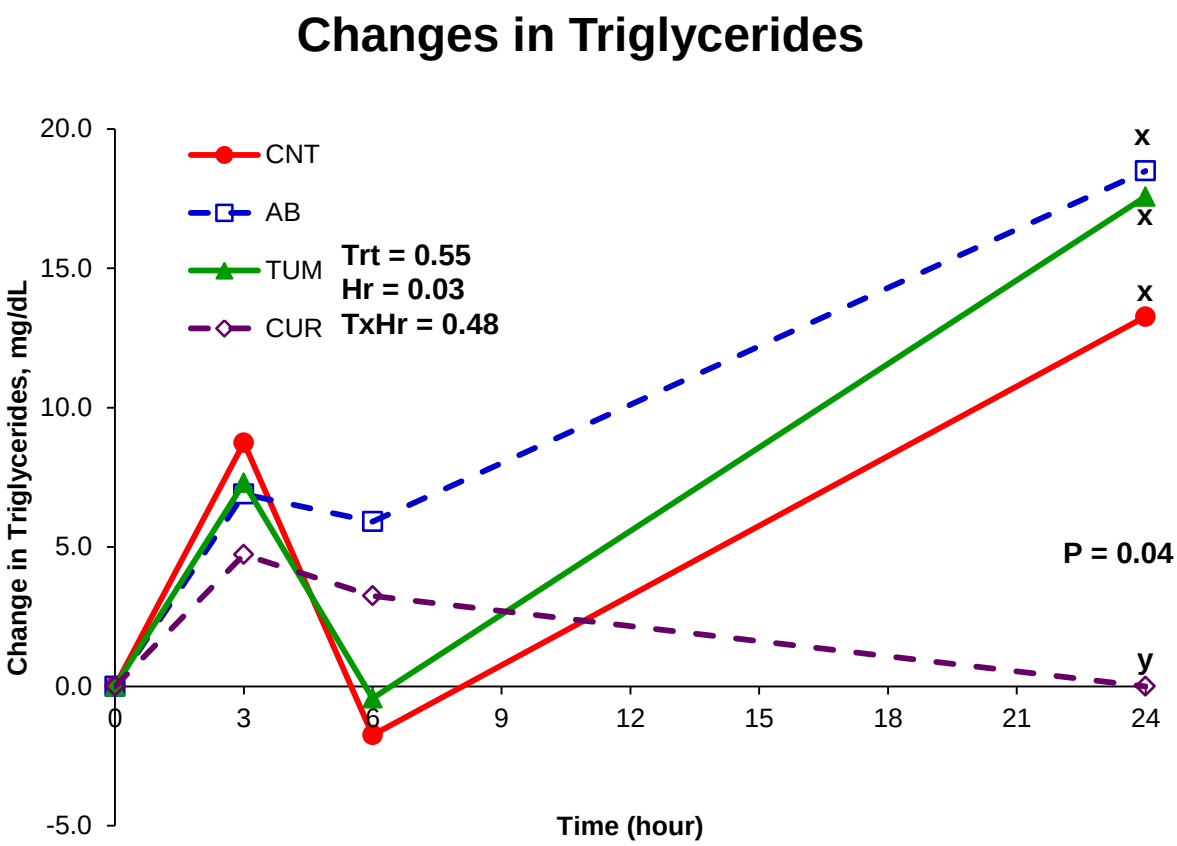


Figure IV.7. Effects of curcumin vs. carbadox on changes in serum triglycerides of nursery pigs during a lipopolysaccharide (LPS) challenge. The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – control, no antibiotic; □ – antibiotic, 55 mg/kg of carbadox; ▲ – 2 g/kg of turmeric powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

CHAPTER V

EXPERIMENT III

EFFECTS OF INCREASING LEVELS OF CURCUMIN ON GROWTH PERFORMANCE AND IMMUNE RESPONSE OF NURSERY PIGS

M. R. Bible, S. D. Carter, K. F. Coble, and H. J. Kim

Oklahoma State University, Stillwater, OK

ABSTRACT

Curcumin is found in the spice turmeric. It is one of the most potent curcuminoids present in turmeric. Curcumin (CUR) has many properties that are potentially beneficial to nursery pigs, such as antimicrobial and anti-inflammatory properties. With this in mind, 2 experiments (Exp.) were designed to determine the effect of different levels of curcumin on growth performance and immune response. Two hundred eighty crossbred (D x (L x Y)) pigs were weaned at 20 d of age, blocked by BW, and stratified by ancestry. Pigs were allotted randomly to 4 dietary treatments, and placed in an environmentally-controlled building in a randomized complete block design. Each experiment consisted of corn-soybean meal based diets with a 4 phase feeding program (SID Lys 1.56, 1.51, 1.31, and 1.25%). ADG (g/d), ADFI (g/d), and G:F were calculated for d 0-21 and 0-42. Exp. 1 (6 reps/trt) used 168 pigs (6.2 kg) with the following treatments: carbadox (55 mg/kg; AB), 20, 40, and 80 mg/kg of CUR. Exp. 2 (7 reps/trt) used 112 pigs (6.0 kg) with the following treatments: carbadox (55 mg/kg; AB), 80, 160, and 320 mg/kg of CUR. On d 20, selected pigs were challenged with an *E. coli* lipopolysaccharide (LPS). Rectal temperatures (RT) were measured and blood collected for analysis of tumor necrosis factor-α (TNF-α), C-reactive protein (CRP), blood urea nitrogen (BUN), glucose, total protein, and triglycerides a 0 and 3, 6, 12, and 24 post-injection (PI). For d 0-21 Exp. 1, there were no differences (P > 0.10) in ADG, ADFI, or G:F. CUR had no effect (P > 0.10) on ADG for d 0-42; however, CUR tended (P = 0.08; quad) to decrease ADFI and increased (P = 0.04; quad) G:F. For Exp. 2, CUR tended (P = 0.08; quad) to

decrease ADG, decreased (P = 0.009; linear) ADFI, and had no effect (P > 0.10) on G:F for d 0-21. For d 0-42, CUR had no effect (P > 0.10) on ADFI, but it decreased (P = 0.02; linear) ADG and tended (P = 0.06; linear) to decrease G:F. For the LPS challenge for Exp. 1, BUN was decreased (P = 0.04; quad) by CUR supplementation at h 0 PI. CUR decreased (P = 0.05; quad) CRP at h 6 PI. For Exp. 2, CUR tended (P = 0.07; linear) to decrease RT at h 0 and decreased (P = 0.02; linear) RT at h 3. TNF-α tended (P = 0.09; linear) to increase as CUR increased at h 6 PI. CRP decreased linearly at h 0 (P = 0.05) and h 6 (P = 0.03) PI and tended to decrease linearly at h 3 (P = 0.06) and h 24 (P = 0.10) PI. CUR decreased (P = 0.03; linear) triglyceride levels at h 24 PI. In conclusion, pigs fed 40 mg/kg of CUR had similar growth performance compared to pigs fed AB and blunted the response of an *E. coli* LPS challenge. In Exp. 2, 80 mg/kg of CUR had similar growth performance compared to an AB. It also decreased the innate immune response of a LPS challenge.

INTRODUCTION

Curcumin is the most active component in turmeric (Lantz et al., 2005; Bengmark et al., 2009). Curcumin was discovered over two centuries ago by Vogel and Pelletier. They reported a “yellow coloring-matter” and named it curcumin. In 1910, Lampe and Milobedzka identified the structure of diferuloylmethane or curcumin (Gupta et al., 2012). Curcumin decreases tumor necrosis factor-α (TNF-α), cyclooxygenase (COX), NF-κB activation, C-reactive protein (CRP), and prostaglandin E2 (Rajasekaran, 2011). In humans, curcumin has alleviated symptoms associated with Crohn’s disease, ulcerative colitis,

ulcers, irritable bowel syndrome, and gastric inflammation, just to name a few (Gupta et al., 2013).

Previous research in Chapter IV showed that when nursery pigs were fed 80 mg/kg of curcumin their growth performance was similar to pigs fed carbadox. Curcumin also attenuated the immune response of an *Escherichia coli* LPS challenge by reducing the concentration of TNF-α.

The objective of this study was to determine the effects of increasing levels of curcumin supplementation on growth performance, as well as, the immune response during an *Escherichia coli* lipopolysaccharide challenge in nursery pigs. To determine the optimum level of curcumin tested in this study to obtain maximum growth performance and a decrease in the immune response.

MATERIALS AND METHODS

Curcumin Analysis

The curcumin powder was analyzed for curcumin, bisdemethoxycurcumin (BDMC), and demethoxycurcumin (DMC) concentration. GAAS, Corporation (Tucson, AZ) performed the analysis using an HPLC. The standards used were greater than 91% pure. Briefly, samples were extracted with an 80:20 solvent mixture of methanol:water. Approximately 2 mL of the supernatant was transferred to an amber HPLC vial and injected into the column. The column type and size was a Kinetex C18, 2.6 µ, 150 x 4.6 mm column.

Animal Care and Feeding

A total of 280 crossbred ((Duroc x (Landrace x Yorkshire)) nursery pigs were utilized in 2 experiments to determine the optimum curcumin supplementation on growth performance and immune response when compared to a subtherapeutic antibiotic. Experiment (Exp.) 1 utilized 168 nursery pigs with an average BW of 6.2 kg, and Exp. 2 used 112 nursery pigs with a beginning average BW of 6.0 kg. All pigs were weaned at 20 d of age and used in a 42-d study. Pigs were blocked by body weight, stratified by ancestry and sex, and allotted randomly to one of four dietary treatments in a randomized complete block design (RCBD). Treatments for Exp. 1 were: 1) control diet + 55 mg/kg of carbadox (AB), 2) control diet + 20 mg/kg of curcumin (20), 3) control diet + 40 mg/kg of curcumin (40), and 4) control diet + 80 mg/kg of curcumin (80). There were 6 replications or pens/treatment with 7 pigs/pen. Exp. 2 dietary treatments were as follows: 1) control diet + 55 mg/kg of carbadox (AB), 2) control diet + 80 mg/kg of curcumin (80), 3) control diet + 160 mg/kg of curcumin (160), and 4) control diet + 320 mg/kg of curcumin (320). This experiment had 7 replications (pens)/treatment with 4 pigs/pen. All diets met or exceeded the requirements listed in the Nutrient Requirements for Swine (NRC, 1998). The curcumin was purchased from Herbal Extracts Plus (Croydon, PA) and was labeled as 95% curcumin powder. Pigs were fed a four-phase feeding program (Tables V.1-8). Phases 1, 2, 3, and 4 were fed for d 0-7, 7-14, 14-21, and 21-42, respectively. All diets were balanced on SID lysine, calcium, and available phosphorus. The SID lysine for each phase was 1.56%, 1.51%, 1.31%, and 1.25%, respectively.

Growth performance (ADG, ADFI, and G:F) data were calculated from the weekly recording of BW and feed disappearance.

All pigs were cared for and handled following the guidelines established by the Oklahoma State University Institutional Animal Care and Use Committee. Pigs were housed in an environmentally-controlled building similar to a commercial setting. Each pen contained a five-hole stainless steel feeder, as well as, a single cup/nipple waterer. Pigs were allowed to consume feed and water *ad libitum*.

Blood Collection

For Exp. 1, two pigs, a barrow and gilt, from each pen were selected to be used for blood collection and a lipopolysaccharide challenge at day 0 of the study. One pig per pen was used for Exp. 2. The pigs were chosen based on the average BW of their respective pen. Blood samples from each pig were collected from the anterior vena cava (jugular) using a 20 gauge 3.8 cm. vacutainer needle with a 10 mL sterile serum tube (BD, Franklin Lakes, NJ), while the pigs were in a supine position. Blood samples were collected at d 0, 7, 14, and 21. The d 0 collection was used as the baseline. Each blood sample was placed on ice after collection, stored in a refrigerator (2-5°C) overnight, and centrifuged. To separate the serum, blood samples were centrifuged for 20 minutes at 2,000 x *g*. A plastic transfer pipet was used to collect the serum. Serum was aliquoted into appropriately labeled microcentrifuge tubes at -20°C until further analyses.

Escherichia Coli Lipopolysaccharide Challenge

Each pig that was used for blood collection was subjected to a lipopolysaccharide (LPS) challenge on d 20 of each experiment. Challenged pigs remained with their other pen mates during the entire 24-hour LPS challenge. *Escherichia coli* O111:B4 LPS (Sigma-Aldrich, Co., St. Loius, MO) was suspended in 9 g/L of sterile saline to a final concentration of 25 μg/kg of BW. Hour 0 baseline blood samples were collected and rectal temperatures and BW were recorded before the LPS was injected. Then, the LPS was administered intraperitoneally in the lower abdomen. Blood was collected, as well as, activity score, rectal temperature, and BW were recorded at 3, 6, 12, and 24 h post-injection (PI). Activity score was the following: 1 = inactive; 2 = moderately inactive; 3 = active; 4 = moderately active; 5 = highly active. Activity score was adapted from behavior descriptions by Hay et al. (2003). Briefly, inactive pigs were sleeping or lying, and showing the pain-related activities of prostrated, huddled up, stiffness, or trembling. Moderately inactive pigs were showing pain-related activities. Awake inactive described pigs that were active. Moderately active pigs were walking, chewing, or licking. Active pigs were running, playing, and showing aggression (Hay et al., 2003). Rectal temperatures were collected to indicate an immune response had occurred and to calculate the change in temperature from h 0. Body weights were used to calculate % BW from hour 0.

Blood Serum Analyses

Serum samples from d 0, h 0 pre-LPS injection, and 3, 6, 12, and 24 h PI were analyzed for BUN, glucose, total protein, triglycerides, CRP, and TNF-α. The change in each blood analyte was calculated using the h 0 time point. Glucose, BUN, total protein, triglycerides, and CRP were analyzed using a Biolis24i Chemistry Analyzer (Carolina Liquid Chemistries Corp., Winston-Salem, NC). Exp. 1 intra-assay CV for BUN, glucose, total, protein, triglycerides, and CRP were 2.8, 1.9, 1.4, 1.4, and 7.6% respectively. Exp. 2 intra-assay CVs were 1.3, 1.1, 1.0, 1.0, and 9.2%, respectively. Manufacturer's directions were followed. Controls, calibrators, and BUN, glucose, total protein, triglycerides, and CRP HS wide range reagents were purchased from VWR (Radnor, PA). An enzyme-linked immunosorbent assay (ELISA) kit was used to test the TNF-α concentrations (R&D Systems, Inc., Minneapolis, MN). Serum samples were analyzed following the manufacturer's instructions. The h 3 PI samples were diluted 5- or 10-fold and the h 6 PI samples were diluted 2-fold. The inter-assay CV was 8.2% and the intra-assay CV was 5.3% for Exp. 1. For Exp. 2, the CV was 4.6% and 5.8% for inter-assay and intra-assay, respectively.

Statistical Analysis

All data were analyzed using a randomized complete block design (SAS Institute, version 9.3). Due to unequally spaced levels of curcumin, coefficients were derived using SAS Proc IML. Growth performance, LPS rectal temperature, LPS blood chemistry, LPS % BW of h 0, and LPS activity score

were analyzed using a GLM procedure. The LPS data was sorted by hour before analysis. Orthogonal polynomial contrasts (linear and quadratic trends) were used to analyze the effects of increasing levels of curcumin powder, as well as, a non-orthogonal contrast of no curcumin vs. curcumin. Changes in LPS blood chemistry and rectal temperature were analyzed using a repeated measures analysis of variance. The first-order autoregressive covariance structure was implemented. Slice effect was used to test for any differences between treatments at different time points. Pen served as the experimental unit. The treatment means are presented as least squares means. Differences were considered significant at the $P < 0.05$ level and a trend at $0.05 < P > 0.10$.

RESULTS

Curcuminoid Concentrations

The curcumin powder that was analyzed for Exp. 1 and 2 contained 58% curcumin, 12% DMC, and 2% BDMC. Table V.9 and Table V.10 shows the calculated mg/kg of the curcuminoid concentrations for the diets for Exp. 1 and Exp. 2, respectively.

Growth Performance

All growth performance data for Exp. 1 are shown in Table V.11. For d 21 and 42 BW, no differences ($P > 0.10$) were observed. No differences ($P > 0.10$) were observed for ADG, ADFI, or G:F for d 0-21. As curcumin levels increased, ADFI decreased ($P = 0.03$; quad) and G:F was improved ($P = 0.05$; linear) for d 21-42. All pigs fed curcumin consumed less ($P = 0.02$) feed/day and had a better

(P = 0.01) G:F compared with pigs fed AB for d 21-42. Daily gain was not affected (P > 0.10) by increasing levels of curcumin for d 0-42. Feed intake tended (P = 0.08; quad) to decrease as curcumin levels increased. Pigs fed AB tended (P = 0.08) to consume more feed in contrast with pigs fed curcumin. As curcumin increased, G:F increased (P = 0.04; quad). Pigs fed curcumin had a better (P = 0.04) G:F than pigs fed AB. A linear (P = <0.001) response was observed for curcumin intake (mg/kg of BW/d), as curcumin increased in the diet so did curcumin intake.

Experiment 2 growth performance data is shown in Table V.12. Body weight tended (P = 0.09; linear) to decrease as curcumin increased in the diet for d 21. For d 0-21, as curcumin increased, ADG tended (P = 0.09; linear) to decrease and ADFI decreased (P = 0.009). Pigs fed AB consumed more (P = 0.03) feed daily than pigs fed curcumin. Curcumin tended (P = 0.08; linear) to decrease gain and decreased (P = 0.01; linear) G:F for d 21-42. There was a decrease in ADG (P = 0.02) and G:F (P = 0.002) for pigs fed curcumin compared with pigs fed AB. No differences (P > 0.10) were observed for ADFI for d 21-42. There was a linear decrease (P = 0.02) noted for d 42 BW as curcumin levels increased BW decreased. Pigs fed curcumin weighed less (P = 0.01) compared with pigs fed AB for d 42. For d 0-42, curcumin had no effect (P > 0.10) on ADFI, but decreased (P = 0.02; linear) daily gain and tended (P = 0.06; linear) to decrease G:F. Compared with pig fed AB, pigs fed curcumin had a lower ADG (P = 0.01) and G:F (P = 0.04). There was a linear increase (P < 0.0001) in curcumin intake on a mg/kg of BW/d basis as curcumin increased in the diet.

LPS Challenge – Rectal Temperature, Activity Score, and BW Lost

Data for rectal temperature, activity score, and % BW of h 0 are presented in Table V.13 for Exp. 1. No differences ($P > 0.10$) were observed for rectal temperatures. Rectal temperatures peaked at h 3 PI and returned to normal by h 24 PI. An hour effect ($P < 0.0001$) was observed for changes in rectal temperatures (Figure V.1). No differences ($P > 0.10$) were observed for changes in rectal temperature during any measure time point. There were no differences ($P > 0.10$) for h 0 or h 3, 6, 12, or 24 PI for activity score. Curcumin ($P = 0.04$; linear) decreased BW lost at h 3 PI. Pigs fed AB lost more ($P = 0.01$) BW of h 0 compared with pigs fed curcumin. Pigs fed AB had greater BW loss than pigs fed curcumin for h 3 ($P = 0.01$) and h 12 ($P = 0.03$) PI, and pigs fed AB tended ($P = 0.08$) to lose more body mass at h 24 PI compared with pigs fed curcumin.

Data for Exp. 2 for rectal temperature, activity score, and % BW of h 0 are shown in Table V.14. Curcumin had no effect ($P > 0.10$) on rectal temperatures at h 6, 12, or 24 PI. But curcumin tended ($P = 0.07$; linear) to decrease h 0 temperatures and decreased ($P = 0.02$) rectal temperatures at h 3 PI. Just like in Exp. 1, temperatures peaked at h 3 PI and returned to normal by 24 PI. There was an hour ($P < 0.0001$) effect for changes in rectal temperature. Curcumin supplementation had no effect ($P > 0.10$) on activity score. Activity score was inversely related to rectal temperature. As temperature increased activity score decreased and vice versa. The % BW of h 0 tended ($P = 0.09$; quad) to decrease at h 24 PI as curcumin levels decreased. No other differences ($P > 0.10$) were observed for % BW of h 0.

LPS Challenge – Blood Analytes

Blood chemistry data are shown in Table V.15 for Exp. 1. Curcumin had no effect (P > 0.10) on TNF-α concentrations. Peak TNF-α levels occurred at h 3 PI and returned back to normal by h 24 PI. Curcumin decreased (P = 0.05; quad) CRP levels at h 6 PI, but had no effect (P > 0.10) on CRP at h 0 or h 3 or 24 PI. An increase (P = 0.04; linear) was observed for BUN, where curcumin increased BUN levels at h 0. Pigs fed curcumin had higher (P = 0.02) levels at h 0 and tended (P = 0.09) to have higher levels of BUN at 3 PI compared with pigs fed AB. No differences (P > 0.10) were observed for glucose, total protein, or triglycerides.

Changes from h 0 for the blood analytes are in Figures V.3-8 for Exp. 1. Changes in TNF-α, CRP, BUN, and triglyceride levels increased (P < 0.0001) in a time-dependent manner, where changes in glucose and total protein decreased (P < 0.0001) in a time-dependent manner. Pigs fed 20, 40, and 80 mg/kg of CUR had a lower (P = 0.05) increase in TNF-α than pigs fed AB at h 3 PI. There were no differences (P > 0.10) observed for h 6 or 24 PI for TNF-α. No differences (P > 0.10) were observed for changes in BUN, glucose, or total protein. However, pigs fed AB tended (P = 0.10) to have a larger increase in triglycerides compared with pigs fed 20 mg/kg of CUR with 40 and 80 mg/kg of CUR intermediate at h 3 and 6 PI.

Data for blood analytes for Exp. 2 are shown in Table V.16. No differences (P > 0.10) were observed for BUN, glucose, or total protein.

Curcumin tended to increase TNF-α at h 6 (P = 0.09; linear) and h 24 (P = 0.09; quad) PI. There were no differences (P > 0.10) observed for h 0 or h 3 PI. However, this cytokine peaked at h 3 PI. Supplementation with curcumin linearly decreased CRP at h 0 (P = 0.05) and h 6 (P = 0.03) PI and tended to linearly decrease CRP levels at h 3 (P = 0.06) and h 24 (P = 0.10) PI. Pigs fed curcumin had lower (P < 0.03) CRP levels at h 0, h 3 PI, and h 6 PI compared with pigs fed AB. Triglycerides were not affected (P <0.10) by curcumin for h 0 or h 3 PI. However, curcumin decreased (P = 0.03; linear) triglycerides at h 24 PI. Also, pigs fed curcumin had lower (P = 0.02) levels of triglycerides at h 6 and 24 PI in contrast with pigs fed AB.

Changes in TNF-α, CRP, BUN, glucose, total protein, and triglycerides for Exp. 2 are in Figures V.9-14. No differences (P > 0.10) were observed for changes in TNF-α, CRP, BUN, glucose, total protein, or triglycerides for Exp. 2. However, TNF-α peaked at h 3 PI and was back to normal by h 24 PI, just like in Exp. 1 (P < 0.0001). Levels of CRP and BUN increased in a time-dependent manner to h 24 PI (P < 0.0001). This same pattern was observed in Exp. 1. Glucose and total protein concentrations decreased until h 6 PI and started to increase by h 24 PI (P < 0.0001), which was similar to Exp. 1. Similar to Exp. 1, Exp. 2 triglyceride levels increased at h 3 PI, decreased at h 6 PI, and started to increase back normal at h 24 PI (P < 0.0001).

DISCUSSION

Previous results from Chapter IV showed that the addition of 80 mg/kg of curcumin had a similar growth response as carbadox in nursery pigs. This level of curcumin also blunted the innate immune response to an *Escherichia coli* LPS challenge. From this study, the concentrations of curcumin for both experimenters were chosen. The objective was to determine the best level of curcumin to supplement to nursery pigs that would have a similar or even better growth and immune response when compared to carbadox.

The curcumin purchased for these experiments was labeled as 95% curcumin. However, after analysis, our curcumin was 58%, 12%, and 2% of curcumin, DMC, and BDMC, respectively. These concentrations are below the normal commercial standards. Anand et al. (2008) reported the average curcuminoid concentrations for curcumin are 77% curcumin, 17% DMC, and 3% BDMC. Technically, the curcumin concentrations are 42% less than what they were supposed to be. Therefore, before feeding curcumin to swine, have it analyzed for the correct levels of curcuminoids. In the case of this study, the lower levels of curcumin did not affect feed intake like the higher levels did. It would be recommended not to feed levels higher than 185.6 mg/kg (320) of curcumin due to the negative effects on gain and feed intake observed.

There is little published research in regards to feeding curcumin to pigs. Yan et al. (2011) reported when an herbal extract mixture (HEM) was fed to growing pigs at 250 mg/kg and 500 mg/kg ADG and ADFI were comparable to

pigs fed apramycin at 30 mg/kg. Black pepper, curcuma, ginger, buckwheat, and type were in the HEM at the ratio of 10:30:35:10:15, respectively (Yan et al., 2011). Therefore, one-third of the mixture was curcuma or 75 and 150 mg/kg, respectively. Exp. 1 has similar results as Yan et al. (2011). Pigs fed curcumin performed similar to pigs fed carbadox. In fact, curcumin decreased feed intake and improved G:F. However, Exp. 2. does not agree with Yan et al. (2011) findings. Curcumin decreased daily gain and intake and increased G:F.

The differences in Exp. 1 and 2 could be the curcumin concentrations in Exp. 2 are too high and curcumin is negatively affecting growth performance. Bille et al. (1985) reported a decrease in growth performance when pigs were fed a turmeric oleoresin. A concentration of 1551 mg/kg of BW/d decreased gain and feed efficiency in pigs. Another study by Ilsley et al. (2005) reported no improvement in growth performance in pigs fed 200 mg/kg of curcumin. These two studies are in agreement with Exp. 2.

A LPS challenge was performed to study the effects of curcumin on the innate immune response. Some of the symptoms that are observed with a LPS challenge are: fever, anorexia, decreased activity, and drowsiness (Moya et al., 2009). In this study, *E. coli* O111:B4 LPS was injected to elicit a proven immune response in nursery pigs (Mandali et al., 2000; Mandali et al., 2002; Smith, 2006; Bible, 2009; Williams et al., 2009). An animal is affected by LPS as if it were live bacteria. It is an outer membrane, cell wall component (Mandali et al., 2002) that activates the immune response. Activation occurs in a step-wise process. The LPS will be shuttled by the LPS binding protein (LBP) to the cluster of

differentiation 14 (CD14). Next, the CD14 will deliver the LPS to the TLR4/MD-2 (toll-like receptor 4/myeloid differentiation protein 2) complex. The binding of LPS to the TLR4/MD-2 complex with activate a pro-inflammatory response by activation of NF-κB (Lu et al., 2008; Bryant et al., 2010). The pro-inflammatory cytokines will activate the metabolism of arachidonic acid, which leads to the production of COX-2. Prostaglandin E2 (PGE2) is activated by COX and PGE2 causes a fever by inducing thermal activation in the hypothalamus (Ogoina, 2011). Van Gucht et al. (2004) stated that fever is an indicator of an innate immune response. Our model used in the study induced decreased animal activity, induced fever and anorexia, and activated TNF-α in both experiments; thus, initiating an immune response. Similar results for this LPS model has been observed in Chapters III and IV.

Other research has reported a similar response to TNF-α during a LPS challenge. Williams et al. (2009) reported an increase in TNF-α, interleukin-6 (IL-6), and IL-1β in a time-dependent manner. The peak hours for TNF-α, IL-1β, and IL-6 were 1 h, 3 h, and 2.5 h post-LPS, respectively, in pigs injected with the same LPS and dose as pigs in our study (William et al., 2009). Another study reported TNF-α was elevated 10-fold by 2 hours after an intraperitoneal injection of LPS *E. coli* K-235 (Webel et al., 1997). Both experiments had peak TNF-α concentrations at h 3 PI. This is similar to the previous research mentioned. It is also similar to the results noted in Chapters III and IV. In these chapters, TNF-α levels peaked at h 3 PI.

In previous studies, curcumin has been shown to decrease a LPS response by decreasing the pro-inflammatory cytokines (Sompamit et al., 2009). There are many possible mechanisms for this response. One mechanism is the ability for curcumin to inhibit NF-κB binding. Zhong et al. (2011) reported that curcumin inhibited the binding of NF-κB to DNA in mice HK-2 (renal) cells infected with LPS. However, curcumin would be inhibiting the binding of LPS to MD-2. It has been reported that curcumin can bind to the MD-2 pocket (Gradisar et al., 2007), thus less binding space available for LPS. Less binding by LPS would lead to a decrease in pro-inflammatory cytokines and less inflammation. It is possible that it might not just be curcumin inhibiting the immune response. The other curcuminoids, DMC and BDMC, could have an effect. Zhang et al. (2008) reported the potency of curcuminoids for decreasing TNF-α and nitric oxide were DMC > BDMC > curcumin. This was in LPS-infected rat microglia. Therefore, the exact mechanism(s) of curcumin is not completely understood. One thing is understood and that is curcumin is a pleiotropic molecule (Gupta et al., 2012).

Our study reported a decrease in TNF-α due to supplementation of curcumin in Exp. 1. Lantz et al. (2005) reported that an organic extract of turmeric and curcumin were capable of inhibiting PGE2 and TNF-α. Another report by Liu et al. (2013b) showed a decrease in TNF-α in pigs experimentally infected with *E. coli*. These pigs were fed 10 mg/kg of turmeric oleoresin. Similar results have been reported in pigs with PRRS virus consuming 10 mg/kg of turmeric oleoresin (Liu et al., 2013a). Chapter IV results for TNF-α are similar

to the results in Exp. 1, where curcumin blunted the production of TNF-α when compared to carbadox.

Now, it should be noted that the TNF-α concentrations in pigs in Exp. 2 were 2-3 times higher than pigs in Exp. 1. Our conclusion for this difference is the LPS. It is possible that the LPS was formulated incorrectly or the wrong LPS was purchased. Whatever the case, the pigs in Exp. 2 experienced symptoms of septic shock. Gram-negative sepsis is a result of an over production of the pro-inflammatory cytokines, abnormal coagulation, and proteolytic cascades, which leads to hypotension, multiple organ failure (Beumeri et al., 2003), and possible death. Sepsis can be defined as an infection that has systemic inflammation and has two or more of the following symptoms: tachycardia, rapid breathing, increased or decreased temperature, or increased or decreased leukocyte count (Annane et al., 2005). Instead of the rectal temperatures increasing like they should, they decreased. The pigs felt cool to the touch and breathed rapidly. There were 3, 0, 2, and 1 pig(s) that had the above mentioned symptoms from treatment AB, 20, 40, and 80, respectively. The pigs fed the AB treatment died due to the symptoms brought by the LPS challenge. However, the pigs fed curcumin recovered and lived until the end of the experiment, except one pig fed 40 mg/kg of curcumin. The pig died between the 2nd and 3rd week (days 35-42) of the phase 4 feeding. The pigs fed curcumin had lower numerical TNF-α concentrations and a smaller increase in TNF-α; therefore, curcumin could have helped reduce the symptoms associated with sepsis. Research has shown that

curcumin inhibits the aggregation of platelets and inhibits thrombosis (Pari et al., 2008), which are symptoms of sepsis.

The pigs in both experiments were less active and thus lost body weight after the LPS injection. These results are similar to other research with pigs and a LPS challenge. As reported by Moya et al. (2006), LPS-challenged pigs spent less time alert during resting. The activity score of the animal and BW lost are more than likely related. If an animal is not active, then their feed consumption will be decreased leading to a decrease in BW. Wright et al. (2000) reported a reduction in feed intake during a LPS challenge. Chapters III and IV results were similar to both experiments in this study. The activity score of the animal was decreased in Chapter IV, as well as, BW was lost post-LPS infection in Chapter III and IV. Pigs fed curcumin in Chapter IV, for the most, had higher activity score and lost less weight BW than pigs fed an antibiotic. In Exp. 1, curcumin helped alleviate these symptoms. Pigs fed curcumin lost less BW and were numerically more active during the LPS challenge. These results are probably due to the lower levels of TNF-α. This cytokine catabolizes muscle. The more TNF-α present in the body the more muscle catabolism thus a reduction in BW. Also, the more TNF-α circulating in the blood will lead to more inflammation in the body. This will cause an animal to be less active. In Exp. 2, curcumin had an effect on activity and pigs lost more BW when fed curcumin. This could be due to some negative effects of too much curcumin in the diet.

The blood analytes BUN, glucose, total protein, and triglycerides were measured during the LPS challenge. Urea nitrogen is an indicator of protein

catabolism in food-deprived or starving animals. Research has reported an increase in plasma urea nitrogen (PUN) during a LPS challenge. The cytokine TNF-α can also increase muscle degradation (Webel et al., 1997). There were similar results reported in Exp. 1 and 2 of this study. Pigs had higher levels of BUN after a peak in TNF-α. This resulted in reduction in BW loss. In Exp. 1, pigs fed curcumin had higher levels of BUN at 24 PI in contrast with pigs fed carbadox. These results are different when compared to Chapter IV results. Pigs fed curcumin in Chapter IV had a lower increase in BUN during the LPS challenge. Exp. 2 coincides with the results reported in Chapter IV. Pigs fed curcumin in Exp. 2 had lower levels of BUN when compared to pigs fed an antibiotic.

Both experiments had lower levels of glucose and increased levels of triglycerides, which is similar to the results reported by Webel et al. (1997). Chapter IV glucose and triglyceride levels were similar to the levels in Exp. 1 and 2. The only exception is in Chapter IV at 24 PI the level of triglycerides was higher than h 0 levels. However, the patterns are similar for both experiments and Chapter IV. Triglycerides increase at h 3 PI, decrease at h 6 PI, and increase at h 24 PI.

Most of the changes in glucose and BUN are due to feed deprivation and inflammation (Webel et a., 1997). Pigs are less likely to consume feed when they are have a fever and are less active. A reduction in blood glucose will occur due to no intake of feed. If glucose (energy) levels decrease, the body will produce energy from other sources, such as fat (triglycerides) and protein (BUN).

The acute phase protein, CRP, is activated in the liver by TNF-α (Liu et al., 2013b). C-reactive protein has a half-life of approximately 12 hours; therefore, it dissipates rather rapidly after the acute phase protein response. The peak of CRP is dependent on several actions, which are: production and liberation of TNF-α, interaction of TNF-α with hepatocytes, synthesis of CRP by the liver, and the buildup of CRP in the plasma part (Moya et al., 2006). As stated earlier, TNF-α increases protein catabolism. The amino acids released during this catabolism are believed to aide in synthesis of acute phase protein by providing fuel for the hepatocytes. The acute phase proteins may increase by 25% or more after an infection (Webel et al., 1997).

Moya et al. (2006) reported peak TNF-α concentrations at h 2 PI with corresponding peak CRP concentrations at h 12 PI. In the current study, the peak TNF-α concentrations were 3 hours after injection and peak CRP levels at 24 h PI. Therefore, it is possible that, in these experiments, the peak CRP levels were missed due to the short half-life of CRP. The peak CRP levels probably increased between 12 and 24 h PI. However, Williams et al. (2009) reported CRP levels started increasing at h 6 PI and continued to increase to h 24 PI. These results do concur with both experiments. In both experiments, the levels of CRP in pigs fed curcumin were lower when compared to carbadox. The levels of CRP remained lower throughout the entire LPS challenge. Curcumin has been shown to decrease CRP (Gupta et al., 2012).

CONCLUSION

In conclusion, in Exp. 1 pigs fed 40 mg/kg of curcumin had similar growth performance compared to pigs fed carbadox and blunted the response of an *E. coli* LPS challenge. In Exp. 2, 80 mg/kg of curcumin had similar growth performance compared to an antibiotic. It also decreased the innate immune response of a LPS challenge. Therefore, the recommended dose of curcumin from this study to be fed to nursery pigs is between 40 and 80 mg/kg of curcumin. Further research should be conducted to evaluate the effects of curcumin levels on gastrointestinal morphology, microbial population, and nutrient digestibility to get a better understanding of the mechanisms of curcumin in digestive tract of nursery pigs.

Table V.1 Diet composition of phase 1 diets for low levels of curcumin (Exp. 1)

	% in diet			
Ingredients	**AB[a]**	**20[a]**	**40[a]**	**80[a]**
Corn	31.22	32.23	32.23	32.22
Soybean meal, dehulled	15.00	15.00	15.00	15.00
Whey, dried	25.00	25.00	25.00	25.00
Lactose	7.00	7.00	7.00	7.00
Plasma, spray-dried	6.00	6.00	6.00	6.00
Fishmeal, menhaden	6.00	6.00	6.00	6.00
Soy protein concentrate	2.21	2.21	2.21	2.21
Granulated fat	4.00	4.00	4.00	4.00
L-lysine HCl	0.20	0.20	0.20	0.20
DL-methionine	0.18	0.18	0.18	0.18
L-threonine	0.07	0.07	0.07	0.07
Dicalcium phosphate	0.71	0.71	0.71	0.71
Limestone	0.45	0.45	0.45	0.45
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.002	0.004	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1585	1601	1601	1601
Crude protein, %	22.9	23.0	23.0	23.0
SID Lysine, %	1.56	1.56	1.56	1.56
Calcium, %	0.90	0.90	0.90	0.90
Available phosphorus, %	0.60	0.60	0.60	0.60

[a]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table V.2 Diet composition of phase 2 diets for low levels of curcumin (Exp. 1)

	% in diet			
Feedstuffs	**AB[a]**	**20[a]**	**40[a]**	**80[a]**
Corn	37.29	38.30	38.30	38.29
Soybean meal, dehulled	20.00	20.00	20.00	20.00
Whey, dried	25.00	25.00	25.00	25.00
Plasma, spray-dried	2.50	2.50	2.50	2.50
Blood cells, spray-dried	1.25	1.25	1.25	1.25
Fish meal, menhaden	4.00	4.00	4.00	4.00
Soy protein concentrate	2.12	2.12	2.12	2.12
Granulated fat	4.00	4.00	4.00	4.00
L-lysine HCl	0.21	0.21	0.21	0.21
DL-methionine	0.21	0.21	0.21	0.21
L-threonine	0.10	0.09	0.09	0.09
Dicalcium phosphate	0.93	0.93	0.93	0.93
Limestone	0.44	0.44	0.44	0.44
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.002	0.004	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1577	1593	1593	1592
Crude protein, %	23.0	23.1	23.1	23.1
SID Lysine, %	1.51	1.51	1.51	1.51
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.55	0.55	0.55	0.55

[a]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table V.3 Diet composition of phase 3 diets for low levels of curcumin (Exp. 1)

	% in diet			
Ingredients	**AB[a]**	**20[a]**	**40[a]**	**80[a]**
Corn	53.01	54.01	54.01	54.00
Soybean meal, dehulled	26.12	26.12	26.12	26.12
Whey, dried	10.00	10.00	10.00	10.00
Blood cells, spray-dried	1.25	1.25	1.25	1.25
Fishmeal, menhaden	2.00	2.00	2.00	2.00
Granulated fat	3.00	3.00	3.00	3.00
L-lysine HCl	0.28	0.27	0.27	0.27
DL-methionine	0.17	0.17	0.17	0.17
L-threonine	0.12	0.12	0.12	0.12
Dicalcium phosphate	1.39	1.39	1.39	1.39
Limestone	0.72	0.72	0.72	0.72
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.002	0.004	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1551	1556	1556	1556
Crude protein, %	20.9	20.9	20.9	20.9
SID Lysine, %	1.31	1.31	1.31	1.31
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.45	0.45	0.45	0.45

[a]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.

[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.

[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.

[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.

[e]Carbadox provided at 55 mg/kg of diet.

Table V.4 Diet composition of phase 4 diets for low levels of curcumin (Exp. 1)

	% in diet			
Ingredients	**AB[a]**	**20[a]**	**40[a]**	**80[a]**
Corn	58.25	59.25	59.25	59.24
Soybean meal, dehulled	34.31	34.31	34.31	34.31
Granulated fat	3.00	3.00	3.00	3.00
L-lysine HCl	0.25	0.25	0.25	0.25
DL-methionine	0.12	0.11	0.11	0.11
L-threonine	0.09	0.09	0.09	0.09
Dicalcium phosphate	1.58	1.58	1.58	1.58
Limestone	0.74	0.74	0.74	0.74
Salt	0.50	0.50	0.50	0.50
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.002	0.004	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1557	1572	1572	1572
Crude protein, %	21.5	21.6	21.6	21.6
SID Lysine, %	1.25	1.25	1.25	1.25
Calcium, %	0.75	0.75	0.75	0.75
Available phosphorus, %	0.37	0.37	0.37	0.37

[a]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table V.5 Diet composition of phase 1 diets for high levels of curcumin (Exp. 2)

	% in diet			
Ingredients	**AB[a]**	**80[a]**	**160[a]**	**320[a]**
Corn	31.23	32.23	32.22	32.21
Soybean meal, dehulled	15.00	15.00	15.00	15.00
Whey, dried	25.00	25.00	25.00	25.00
Lactose	7.00	7.00	7.00	7.00
Plasma, spray-dried	6.00	6.00	6.00	6.00
Fishmeal, menhaden	6.00	6.00	6.00	6.00
Soy protein concentrate	2.21	2.21	2.21	2.21
Granulated fat	4.00	4.00	4.00	4.00
L-lysine HCl	0.20	0.20	0.20	0.20
DL-methionine	0.18	0.18	0.18	0.18
L-threonine	0.07	0.07	0.07	0.07
Dicalcium phosphate	0.71	0.71	0.71	0.71
Limestone	0.45	0.45	0.45	0.45
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.008	0.016	0.032
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1585	1601	1601	1600
Crude protein, %	22.9	23.0	23.0	23.0
SID Lysine, %	1.56	1.56	1.56	1.56
Calcium, %	0.90	0.90	0.90	0.90
Available phosphorus, %	0.60	0.60	0.60	0.60

[a]AB = antibiotic; 80 = 80 mg/kg curcumin powder; 160 = 160 mg/kg curcumin powder; 320 = 320 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table V.6 Diet composition of phase 2 diets for high levels of curcumin (Exp. 2)

	% in diet			
Feedstuffs	**AB[a]**	**80[a]**	**160[a]**	**320[a]**
Corn	37.30	38.29	38.28	38.27
Soybean meal, dehulled	20.00	20.00	20.00	20.00
Whey, dried	25.00	25.00	25.00	25.00
Plasma, spray-dried	2.50	2.50	2.50	2.50
Blood cells, spray-dried	1.25	1.25	1.25	1.25
Fish meal, menhaden	4.00	4.00	4.00	4.00
Soy protein concentrate	2.12	2.12	2.12	2.12
Granulated fat	4.00	4.00	4.00	4.00
L-lysine HCl	0.21	0.21	0.21	0.21
DL-methionine	0.21	0.21	0.21	0.21
L-threonine	0.10	0.09	0.09	0.09
Dicalcium phosphate	0.93	0.93	0.93	0.93
Limestone	0.44	0.44	0.44	0.44
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.008	0.016	0.032
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1577	1593	1592	1592
Crude protein, %	23.0	23.0	23.0	23.0
SID Lysine, %	1.51	1.51	1.51	1.51
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.55	0.55	0.55	0.55

[a]AB = antibiotic; 80 = 80 mg/kg curcumin powder; 160 = 160 mg/kg curcumin powder; 320 = 320 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table V.7 Diet composition of phase 3 diets for high levels of curcumin (Exp. 2)

	% in diet			
Ingredients	**AB[a]**	**80[a]**	**160[a]**	**320[a]**
Corn	53.01	54.01	54.00	53.99
Soybean meal, dehulled	26.12	26.12	26.12	26.12
Whey, dried	10.00	10.00	10.00	10.00
Blood cells, spray-dried	1.25	1.25	1.25	1.25
Fishmeal, menhaden	2.00	2.00	2.00	2.00
Granulated fat	3.00	3.00	3.00	3.00
L-lysine HCl	0.28	0.27	0.27	0.27
DL-methionine	0.17	0.17	0.17	0.17
L-threonine	0.12	0.12	0.12	0.12
Dicalcium phosphate	1.39	1.39	1.39	1.39
Limestone	0.72	0.72	0.72	0.72
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.008	0.016	0.032
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1551	1556	1556	1556
Crude protein, %	20.9	20.9	20.9	20.9
SID Lysine, %	1.31	1.31	1.31	1.31
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.45	0.45	0.45	0.45

[a]AB = antibiotic; 80 = 80 mg/kg curcumin powder; 160 = 160 mg/kg curcumin powder; 320 = 320 mg/kg curcumin powder.

[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.

[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.

[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.

[e]Carbadox provided at 55 mg/kg of diet.

Table V.8 Diet composition of phase 4 diets for high levels of curcumin (Exp. 2)

	% in diet			
Ingredients	**AB[a]**	**80[a]**	**160[a]**	**320[a]**
Corn	58.25	59.24	59.23	59.22
Soybean meal, dehulled	34.31	34.31	34.31	34.31
Granulated fat	3.00	3.00	3.00	3.00
L-lysine HCl	0.25	0.25	0.25	0.25
DL-methionine	0.12	0.11	0.11	0.11
L-threonine	0.09	0.09	0.09	0.09
Dicalcium phosphate	1.58	1.58	1.58	1.58
Limestone	0.74	0.74	0.74	0.74
Salt	0.50	0.50	0.50	0.50
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	----	----	----
Curcumin powder	----	0.008	0.016	0.032
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	1557	1572	1572	1572
Crude protein, %	21.5	21.6	21.6	21.6
SID Lysine, %	1.25	1.25	1.25	1.25
Calcium, %	0.75	0.75	0.75	0.75
Available phosphorus, %	0.37	0.37	0.37	0.37

[a]AB = antibiotic; 80 = 80 mg/kg curcumin powder; 160 = 160 mg/kg curcumin powder; 320 = 320 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table V.9. Calculated curcuminoid concentrations of low levels of curcumin powder[a] fed to nursery pigs (Exp. 1)

Curcumin (mg/kg of diet)	Curcuminoid (mg/kg of diet)		
	CUR[b]	DMC[c]	BDMC[d]
20	11.6	2.4	0.41
40	23.2	4.8	0.81
80	46.4	9.6	1.6

[a]Curcumin powder = 57.99% curcumin, 12.02% demethoxycurcumin, and 2.03% bisdemethoxycurcumin
[b]CUR = curcumin
[c]DMC = demethoxycurcumin
[d]BDMC = bisdemethoxycurcumin

Table V.10. Calculated curcuminoid concentrations of high levels of curcumin powder[a] fed to nursery pigs (Exp. 2)

Curcumin (mg/kg of diet)	Curcuminoid (mg/kg of diet)		
	CUR[b]	DMC[c]	BDMC[d]
80	46.4	9.6	1.6
160	92.8	19.2	3.2
320	185.6	38.5	6.5

[a]Curcumin powder = 57.99% curcumin, 12.02% demethoxycurcumin, and 2.03% bisdemethoxycurcumin
[b]CUR = curcumin
[c]DMC = demethoxycurcumin
[d]BDMC = bisdemethoxycurcumin

Table V.11. Effects of low levels of curcumin powder on growth performance of nursery pigs[a] (Exp. 1)

	Treatments[b]					P =		
	AB	20	40	80	SE	Lin	Quad	A vs C[c]
BW, kg								
d 0	6.3	6.2	6.2	6.3	0.02	0.56	0.19	0.17
d 7	6.7	6.7	6.7	6.7	0.08	0.89	0.60	0.73
d 14	8.3	8.3	8.3	8.3	0.18	0.76	0.84	0.70
d 21	11.2	11.4	10.9	11.3	0.29	0.97	0.65	0.98
d 42	25.4	25.4	24.8	25.1	0.66	0.67	0.73	0.72
ADG, g/d								
d 0-7	53	61	68	60	10.0	0.65	0.35	0.39
d 7-14	226	234	228	237	18.2	0.72	0.97	0.39
d 14-21	362	363	312	346	15.4	0.30	0.12	0.24
d 0-21	219	225	206	219	11.7	0.83	0.57	0.85
d 21-42	693	685	674	677	22.6	0.62	0.72	0.60
d 0-42	442	441	427	435	14.8	0.65	0.62	0.64
ADFI, g/d								
d 0-7	181	196	193	190	6.5	0.57	0.21	0.15
d 7-14	318	343	339	328	15.4	0.85	0.28	0.32
d 14-21	616	615	593	591	17.6	0.27	0.76	0.43
d 0-21	382	393	383	380	11.9	0.74	0.70	0.82
d 21-42	1304	1190	1081	1162	50.7	0.07	0.03	0.02
d 0-42	794	761	704	746	26.1	0.18	0.08	0.08
G:F								
d 0-7	0.280	0.304	0.352	0.316	0.0540	0.61	0.47	0.49
d 7-14	0.709	0.687	0.670	0.724	0.0307	0.66	0.23	0.67
d 14-21	0.585	0.590	0.523	0.585	0.0181	0.73	0.05	0.37
d 0-21	0.571	0.574	0.536	0.577	0.0184	0.97	0.21	0.69
d 21-42	0.539	0.577	0.628	0.585	0.0152	0.05	0.004	0.01
d 0-42	0.559	0.579	0.606	0.584	0.0117	0.14	0.04	0.04
Curcumin Consumed, mg/kg BW/d								
	0	0.76	1.43	3.01	0.042	<0.0001	0.29	<0.0001

[a]Least squares means for 6 replications/treatment.
[b]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[c]A vs C = control versus all curcumin treatments.

Table V.12. Effects of high levels of curcumin powder on growth performance of nursery pigs[a] (Exp. 2)

	Treatments[b]					P =		
	AB	80	160	320	SE	Lin	Quad	A vs C[c]
BW, kg								
d 0	6.0	6.0	6.0	6.0	0.03	0.67	0.76	0.77
d 7	7.7	7.5	7.5	7.5	0.08	0.12	0.28	0.04
d 14	10.0	9.5	9.6	9.2	0.14	0.003	0.40	0.003
d 21	11.9	11.7	11.9	11.3	0.25	0.09	0.54	0.31
d 42	22.7	21.1	21.5	20.6	0.51	0.02	0.40	0.01
ADG, g/d								
d 0-7	236	205	212	206	11.1	0.15	0.23	0.04
d 7-14	327	287	292	250	17.9	0.01	0.80	0.03
d 14-21	280	324	330	296	33.4	0.87	0.25	0.35
d 0-21	281	272	278	251	11.6	0.09	0.54	0.30
d 21-42	634	550	569	549	26.5	0.08	0.20	0.02
d 0-42	439	396	408	384	13.1	0.02	0.38	0.01
ADFI, g/d								
d 0-7	298	271	268	277	12.7	0.36	0.14	0.09
d 7-14	470	418	428	402	15.2	0.01	0.29	0.006
d 14-21	585	603	569	512	29.4	0.05	0.41	0.48
d 0-21	451	431	421	397	13.2	0.009	0.766	0.03
d 21-42	1003	998	982	1019	44.5	0.80	0.64	0.96
d 0-42	698	685	672	675	19.9	0.43	0.57	0.38
G:F								
d 0-7	0.791	0.756	0.802	0.743	0.0287	0.36	0.62	0.47
d 7-14	0.692	0.682	0.683	0.626	0.0327	0.15	0.60	0.45
d 14-21	0.465	0.549	0.586	0.577	0.0543	0.19	0.28	0.11
d 0-21	0.621	0.633	0.664	0.634	0.0253	0.69	0.31	0.45
d 21-42	0.633	0.551	0.577	0.542	0.0186	0.01	0.18	0.002
d 0-42	0.628	0.579	0.608	0.572	0.0164	0.06	0.72	0.04
Curcumin Consumed, mg/kg BW/d								
	0	2.86	5.53	11.5	0.223	<0.0001	0.50	<0.0001

[a]Least squares means for 7 replications/treatment.
[b]AB = antibiotic; 80 = 80 mg/kg curcumin powder; 160 = 160 mg/kg curcumin powder; 320 = 320 mg/kg curcumin powder.
[c]A vs C = control versus all curcumin treatments.

Table V.13. Effects of low levels of curcumin powder on BW loss[a], rectal temperature[a], and activity score[a] of nursery pigs during a LPS[b] challenge (Exp. 1)

	Treatments[c]					P =		
	AB	20	40	80	SE	Lin	Quad	A vs C[d]
Rectal temperature, °C								
h 0	39.7	39.6	39.5	39.7	0.11	0.95	0.28	0.61
h 3	40.6	41.1	40.8	41.0	0.27	0.63	0.67	0.33
h 6	40.2	40.8	40.1	40.7	0.31	0.52	0.78	0.45
h 12	39.9	39.9	39.6	39.7	0.21	0.45	0.43	0.43
h 24	39.3	39.4	39.3	39.5	0.09	0.31	0.55	0.60
Activity score[e]								
h 0	5.0	5.0	4.9	5.0	0.04	0.87	0.22	0.57
h 3	2.1	2.0	2.3	2.0	0.16	0.86	0.48	1.00
h 6	1.8	2.1	2.3	2.3	0.28	0.24	0.33	0.17
h 12	3.4	3.9	3.8	3.6	0.28	0.82	0.26	0.28
h 24	4.9	4.6	4.8	4.9	0.10	0.35	0.20	0.44
% BW of h 0								
h 3	95.2	96.3	96.9	96.4	0.36	0.04	0.02	0.01
h 6	94.5	95.6	95.3	95.0	0.40	0.70	0.12	0.13
h 12	93.5	96.5	96.1	96.3	0.92	0.12	0.13	0.03
h 24	96.2	98.6	98.2	97.8	0.85	0.37	0.14	0.08

[a]Least squares means for 6 replications/treatment.
[b]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[c]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[d]A vs C = antibiotic versus all curcumin treatments.
[e]Activity score – 1 = inactive; 2 = moderately inactive; 3 = active; 4 = moderately active; 5 = highly active.

Table V.14. Effects of high levels of curcumin powder on BW loss[a], rectal temperature[a], and activity score of nursery pigs during a LPS[b] challenge (Exp. 2)

	Treatments[c]					P =		
	AB	80	160	320	SE	Lin	Quad	A vs C[d]
Rectal temperature, °C								
h 0	39.8	39.6	39.7	39.5	0.13	0.07	0.93	0.16
h 3	41.1	41.2	41.1	40.8	0.14	0.02	0.20	0.56
h 6	40.7	40.8	40.5	40.5	0.13	0.29	0.98	0.71
h 12	40.3	40.2	40.2	40.0	0.14	0.12	0.56	0.46
h 24	39.4	39.3	39.4	39.5	0.11	0.51	0.67	0.95
Activity score[e]								
h 0	5.0	5.0	5.0	5.0	0.00	0.00	0.00	0.00
h 3	3.1	2.7	2.7	2.9	0.22	0.52	0.19	0.15
h 6	3.3	3.1	3.0	3.3	0.19	0.95	0.23	0.51
h 12	4.0	3.7	3.4	3.7	0.22	0.38	0.13	0.14
h 24	5.0	4.9	4.9	4.9	0.13	0.53	0.54	0.55
% BW of h 0								
h 3	98.4	98.1	98.4	98.1	0.50	0.79	0.93	0.68
h 6	97.1	96.5	96.6	96.2	0.59	0.37	0.79	0.36
h 12	96.4	96.2	96.3	96.1	0.74	0.86	0.97	0.85
h 24	98.3	96.0	97.6	98.5	0.72	0.34	0.09	0.27

[a]Least squares means for 7 replications/treatment.
[b]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[c]AB = antibiotic; 80 = 80 mg/kg curcumin powder; 160 = 160 mg/kg curcumin powder; 320 = 320 mg/kg curcumin powder.
[d]A vs C = antibiotic versus all curcumin treatments.
[e]Activity score – 1 = inactive; 2 = moderately inactive; 3 = active; 4 = moderately active; 5 = highly active.

Table V.15. Effects of low levels of curcumin powder on blood analytes[a] of nursery pigs during a LPS[b] challenge (Exp. 1)

	Treatment[c]					P =		
	AB	20	40	80	SE	Lin	Quad	A vs C[d]
TNF-α[e], pg/mL								
h 0	91	86	103	99	7.7	0.32	0.74	0.58
h 3	15911	8503	9119	10594	3268	0.41	0.18	0.11
h 6	1947	2426	2573	2805	481	0.27	0.68	0.30
h 24	124	143	169	201	36	0.15	0.91	0.31
CRP[f], mg/mL								
h 0	1.02	0.84	0.99	0.90	0.25	0.68	0.95	0.65
h 3	1.19	0.91	0.86	0.70	0.19	0.31	0.20	0.98
h 6	1.59	1.55	1.15	1.11	0.19	0.65	0.05	0.25
h 24	3.14	2.94	2.55	2.55	0.37	0.58	0.25	0.67
BUN[g], mg/dL								
h 0	5.5	4.0	5.8	6.1	0.6	0.14	0.04	0.02
h 3	5.7	4.5	5.9	5.8	0.3	0.29	0.23	0.09
h 6	6.5	6.3	7.4	7.6	0.9	0.97	0.22	0.39
h 24	9.9	10.1	13.7	12.5	2.5	0.75	0.29	0.51
Glucose, mg/dL								
h 0	105	104	104	105	3.9	0.80	0.91	0.82
h 3	86.2	88.1	84.4	90.6	3.6	0.93	0.74	0.81
h 6	72.5	68.1	64.1	67.0	5.8	0.51	0.54	0.97
h 24	98.0	97.0	94.7	102.3	5.0	0.74	0.67	0.82
Total protein, g/dL								
h 0	4.9	4.8	4.9	4.7	0.13	0.80	0.59	0.93
h 3	4.2	4.2	4.2	4.1	0.13	0.83	0.65	0.96
h 6	4.1	4.0	4.1	3.9	0.12	0.86	0.49	0.89
h 24	4.4	4.4	4.5	4.4	0.10	0.80	0.85	0.75
Triglycerides, mg/L								
h 0	24.7	31.5	26.7	25.1	4.1	0.29	0.49	0.22
h 3	52.2	41.5	43.8	43.5	7.1	0.30	0.75	0.55
h 6	30.4	19.0	25.7	23.8	4.4	0.14	0.89	0.16
h 24	38.0	35.3	32.0	35.9	4.4	0.54	0.70	0.99

[a]Least squares means for 6 replications/treatment.
[b]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[c]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[d]A vs C = antibiotic versus all curcumin treatments.
[e]TNF-α = tumor necrosis factor-α.
[f]CRP = C-reactive protein.
[g]BUN = blood urea nitrogen.

Table V.16. Effects of high levels of curcumin powder on blood analytes[a] of nursery pigs during a LPS[b] challenge (Exp. 2)

	Treatment[c]					P =		
	AB	80	160	320	SE	Lin	Quad	A vs C[d]
TNF-α[e], pg/mL								
h 0	99	105	95	111	9.5	0.45	0.61	0.64
h 3	4059	3335	3914	4833	915	0.42	0.49	0.98
h 6	652	1233	1035	1574	231	0.09	0.65	0.24
h 24	124	104	98	137	16	0.43	0.09	0.57
CRP[f], mg/mL								
h 0	1.75	0.59	0.67	0.36	0.39	0.05	0.21	0.02
h 3	1.66	0.64	0.73	0.40	0.39	0.06	0.30	0.03
h 6	1.96	1.01	1.20	0.70	0.32	0.03	0.39	0.02
h 24	3.99	3.34	2.99	2.63	0.55	0.10	0.58	0.13
BUN[g], mg/dL								
h 0	6.5	6.8	6.3	10.4	1.9	0.15	0.41	0.56
h 3	6.7	6.9	6.1	10.1	1.8	0.17	0.34	0.63
h 6	7.4	7.9	7.4	10.9	1.9	0.18	0.50	0.54
h 24	11.9	10.6	9.7	12.8	1.9	0.65	0.26	0.70
Glucose, mg/dL								
h 0	102	102	105	102	5.6	0.95	0.70	0.84
h 3	91.4	98.2	97.7	89.9	6.0	0.71	0.27	0.58
h 6	77.4	74.0	78.9	79.9	4.7	0.54	0.82	0.96
h 24	86.3	86.9	90.9	80.6	5.6	0.47	0.34	0.98
Total protein, g/dL								
h 0	5.0	4.8	4.8	4.9	0.20	0.94	0.61	0.66
h 3	4.2	4.1	3.8	4.1	0.22	0.63	0.33	0.45
h 6	4.0	3.9	3.7	3.9	0.19	0.79	0.26	0.42
h 24	4.5	4.5	4.4	4.4	0.19	0.64	0.78	0.67
Triglycerides, mg/L								
h 0	37.9	33.6	40.5	33.4	9.1	0.81	0.82	0.84
h 3	49.8	38.4	40.9	33.7	8.7	0.26	0.74	0.24
h 6	27.9	15.5	19.6	17.1	3.7	0.13	0.19	0.02
h 24	38.8	26.3	30.7	22.1	4.2	0.03	0.56	0.02

[a]Least squares means for 7 replications/treatment.
[b]LPS = *Escherichia coli* O111:B4 lipopolysaccharide.
[c]AB = antibiotic; 80 = 80 mg/kg curcumin powder; 160 = 160 mg/kg curcumin powder; 320 = 320 mg/kg curcumin powder.
[d]A vs C = antibiotic versus all curcumin treatments.
[e]TNF-α = tumor necrosis factor-α.
[f]CRP = C-reactive protein.
[g]BUN = blood urea nitrogen.

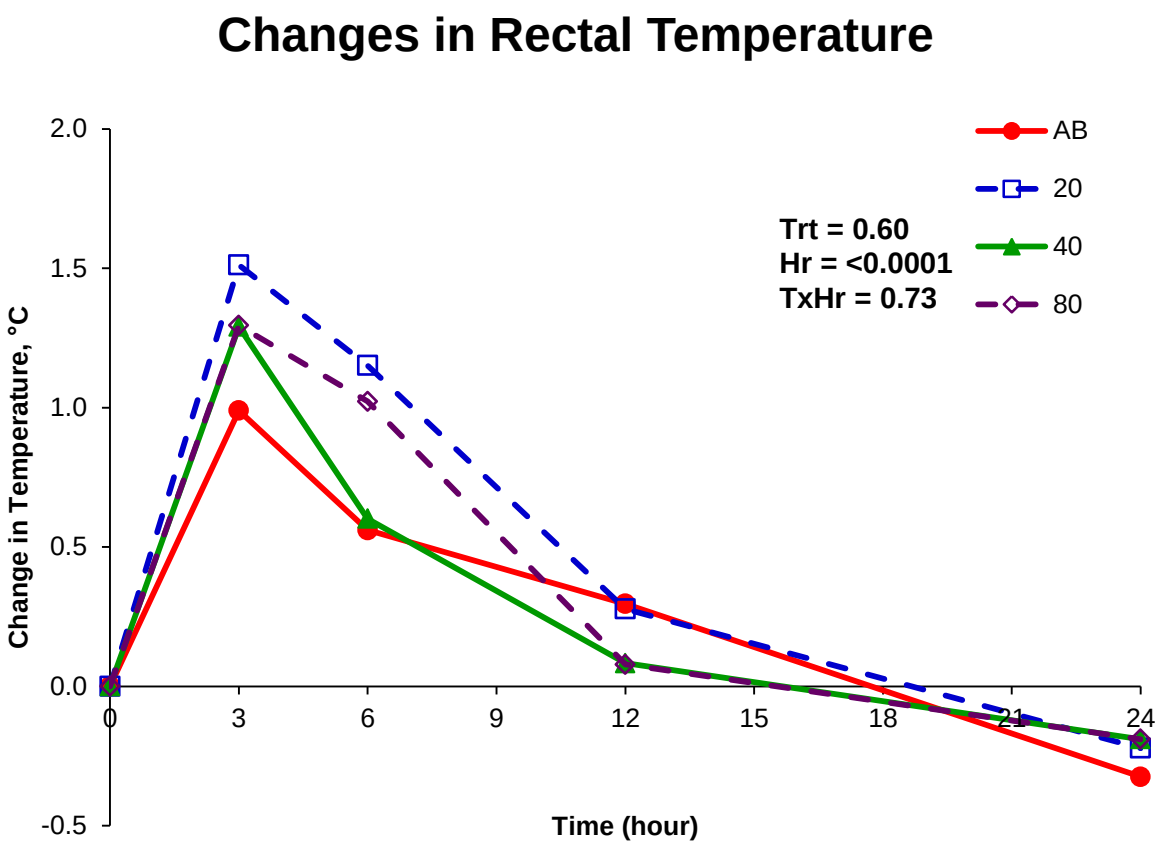


Figure V.1. Effects of low levels of curcumin on changes in rectal temperature of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 1). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 20 mg/kg of curcumin powder; ▲ – 20 mg/kg of curcumin powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

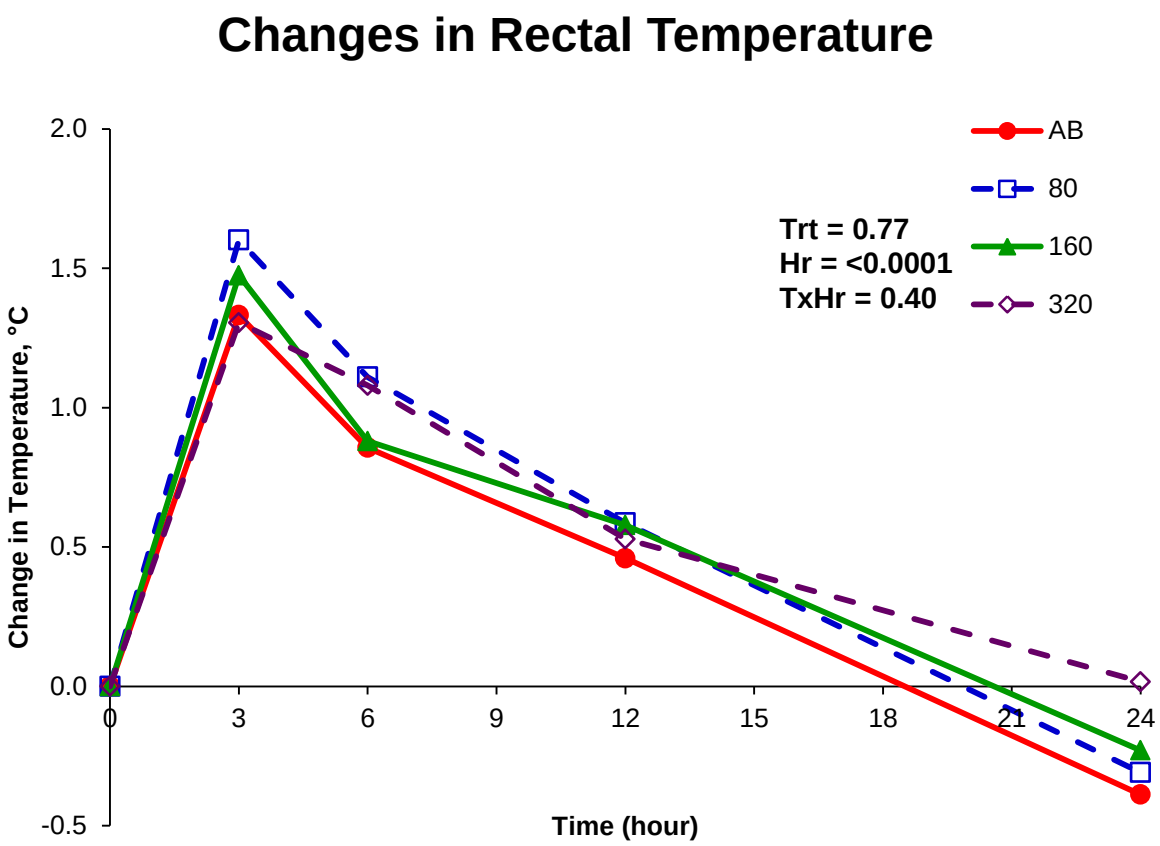


Figure V.2. Effects of high levels of curcumin on changes in rectal temperature of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 2). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 80 mg/kg of curcumin powder; ▲ –160 mg/kg of curcumin powder; ◊ – 320 mg/kg of curcumin powder. There were 7 replications/treatment.

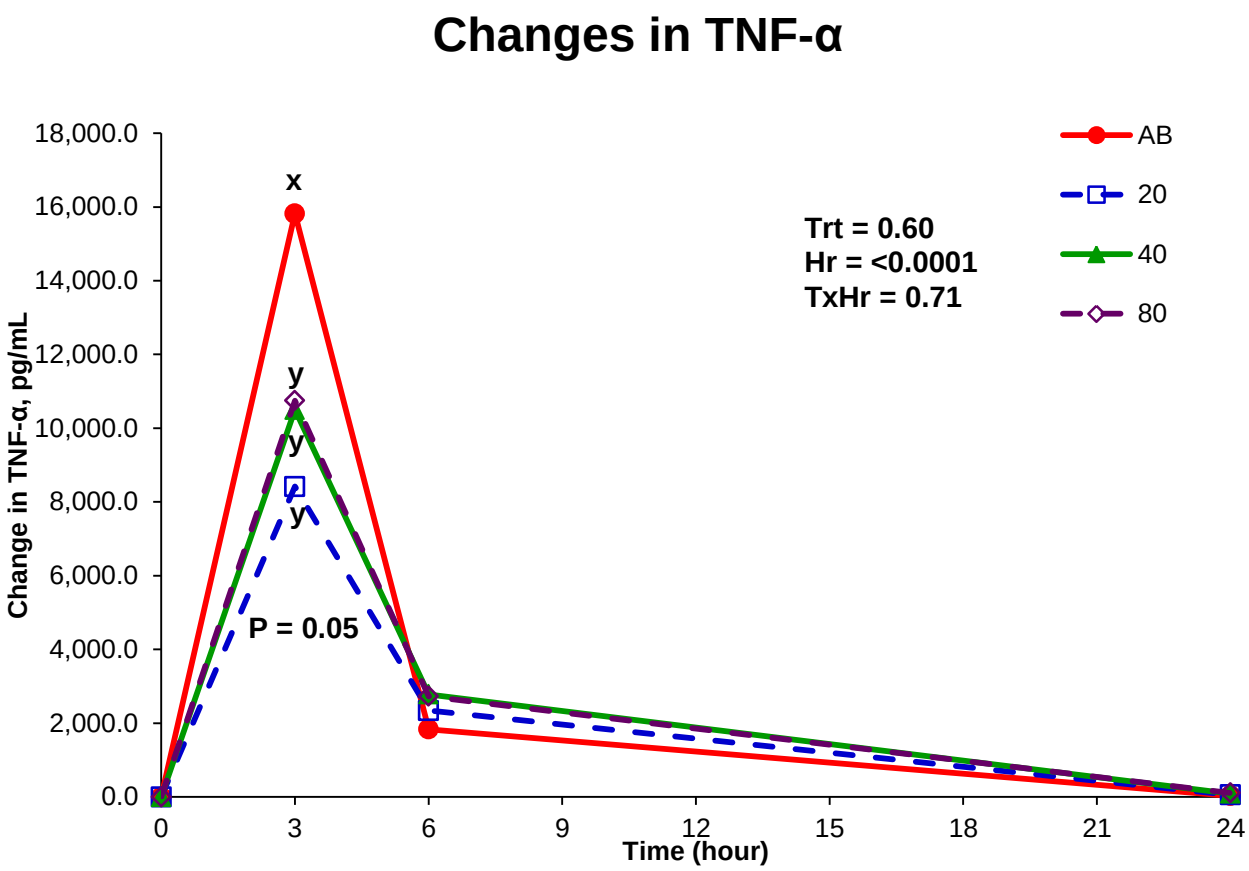


Figure V.3. Effects of low levels of curcumin on changes in tumor necrosis factor-α (TNF-α) of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 1). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 20 mg/kg of curcumin powder; ▲ – 20 mg/kg of curcumin powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

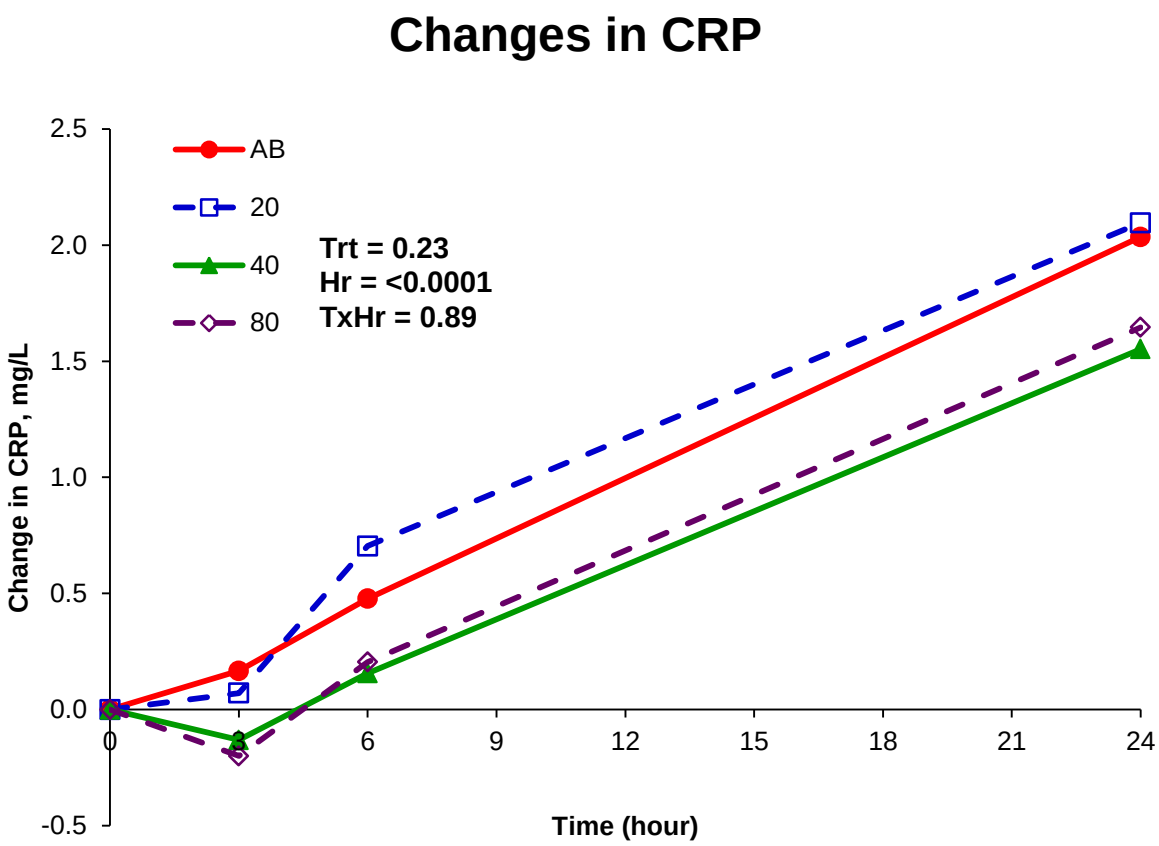


Figure V.4. Effects of low levels of curcumin on changes in C-reactive protein (CRP) of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 1). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 20 mg/kg of curcumin powder; ▲ – 20 mg/kg of curcumin powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

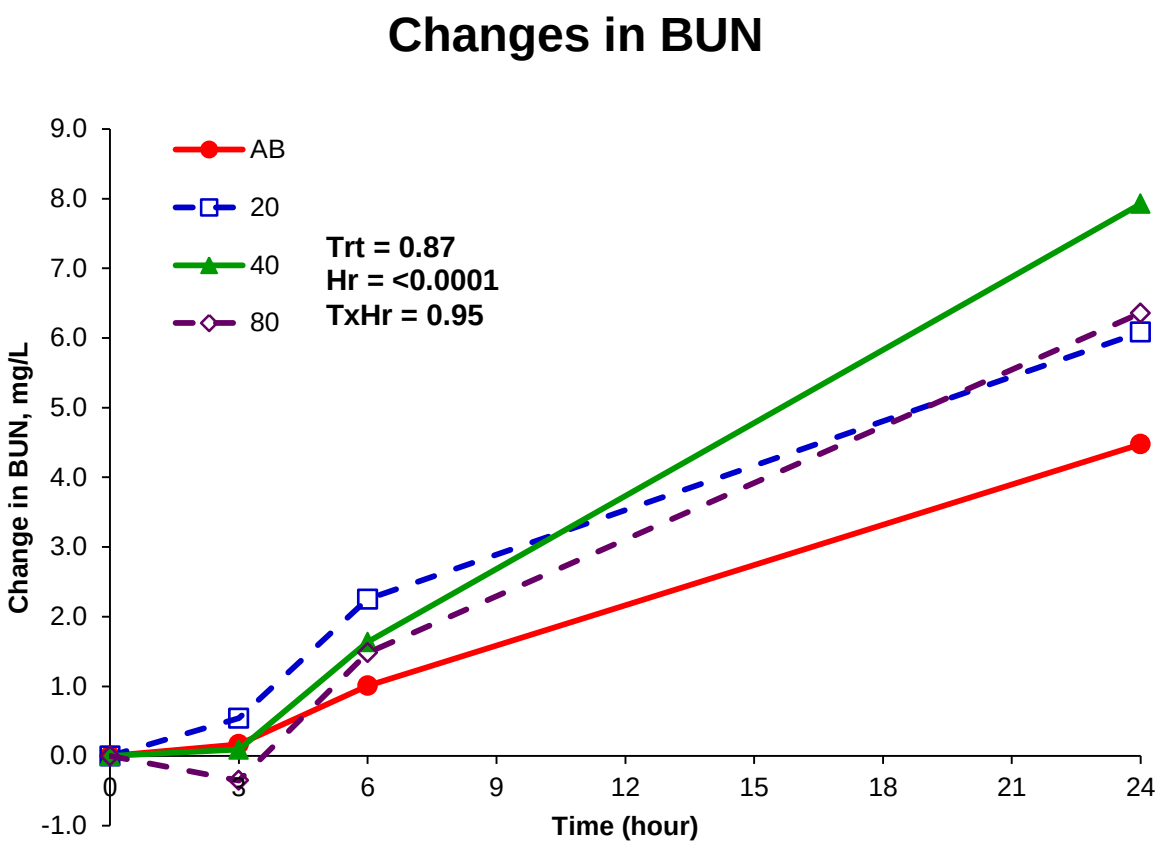


Figure V.5. Effects of low levels of curcumin on changes in blood urea nitrogen (BUN) of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 1). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 20 mg/kg of curcumin powder; ▲ – 20 mg/kg of curcumin powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

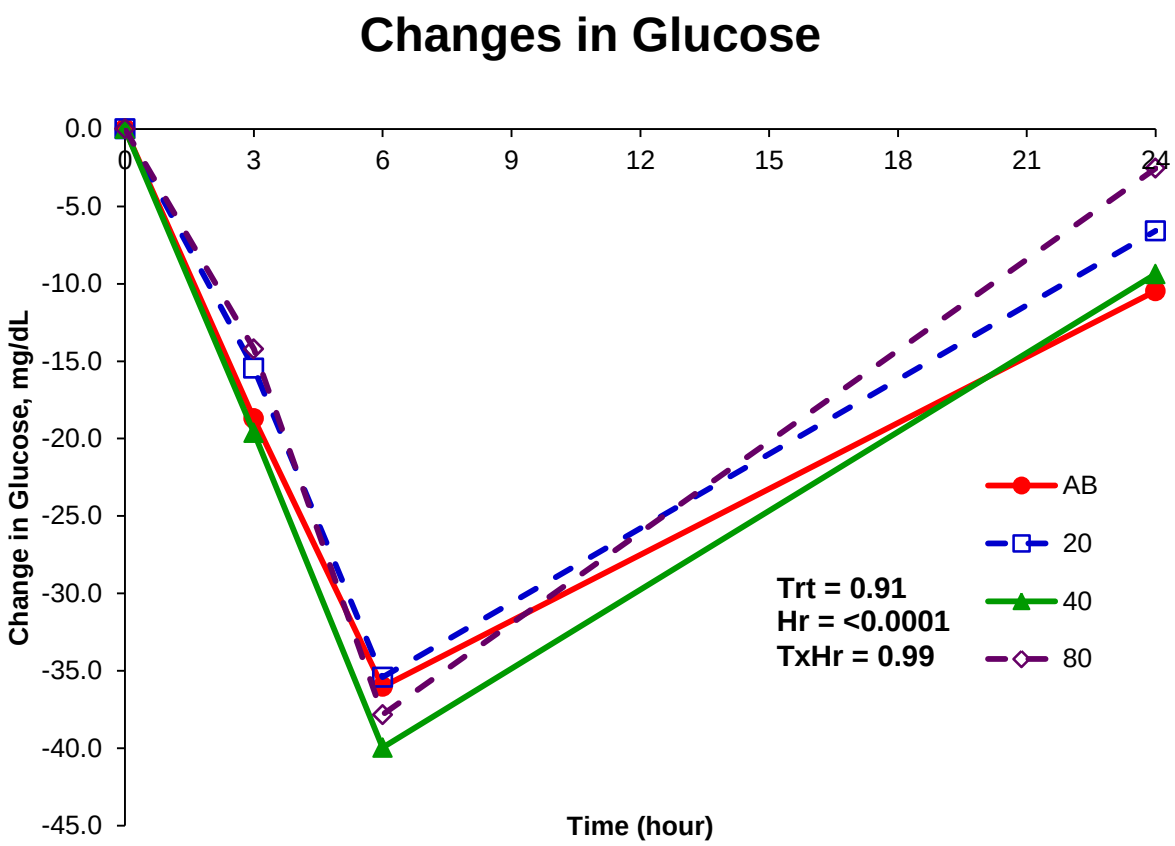


Figure V.6. Effects of low levels of curcumin on changes in glucose of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 1). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 20 mg/kg of curcumin powder; ▲ – 20 mg/kg of curcumin powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

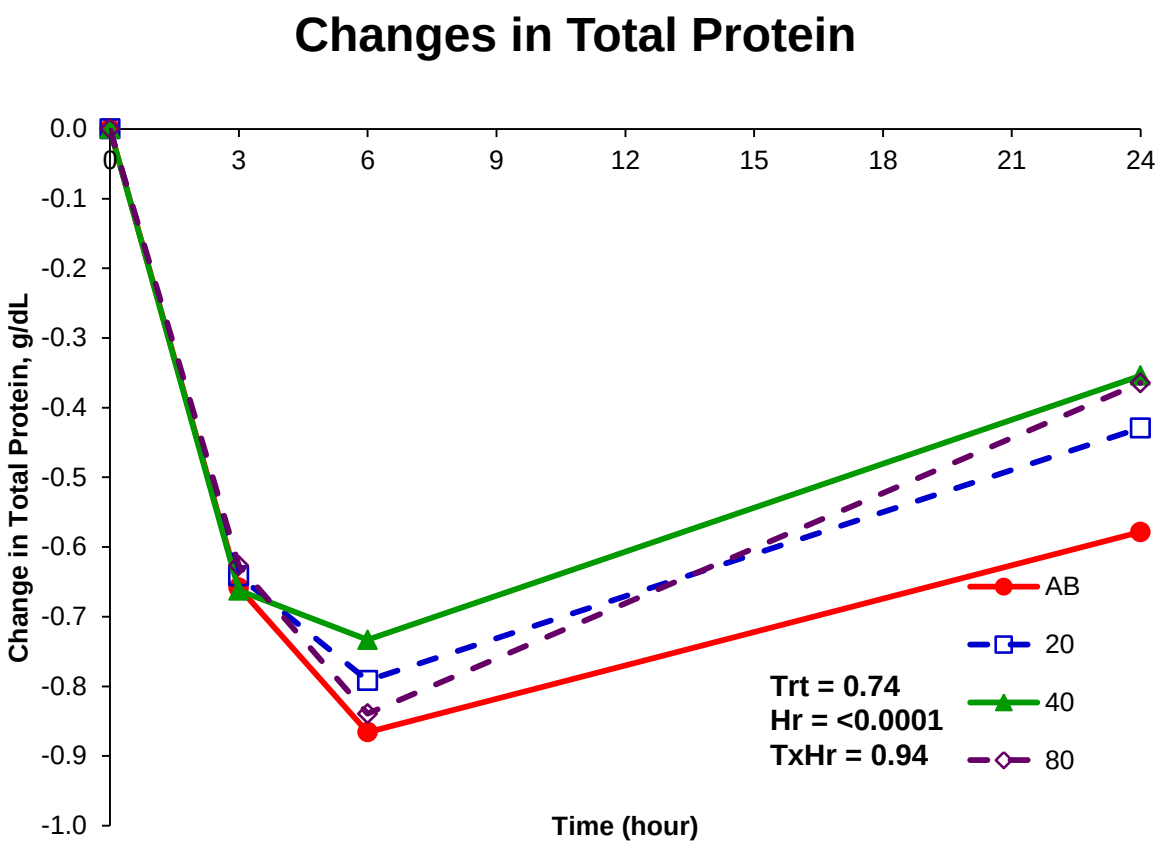


Figure V.7. Effects of low levels of curcumin on changes in total protein of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 1). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 20 mg/kg of curcumin powder; ▲ – 20 mg/kg of curcumin powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

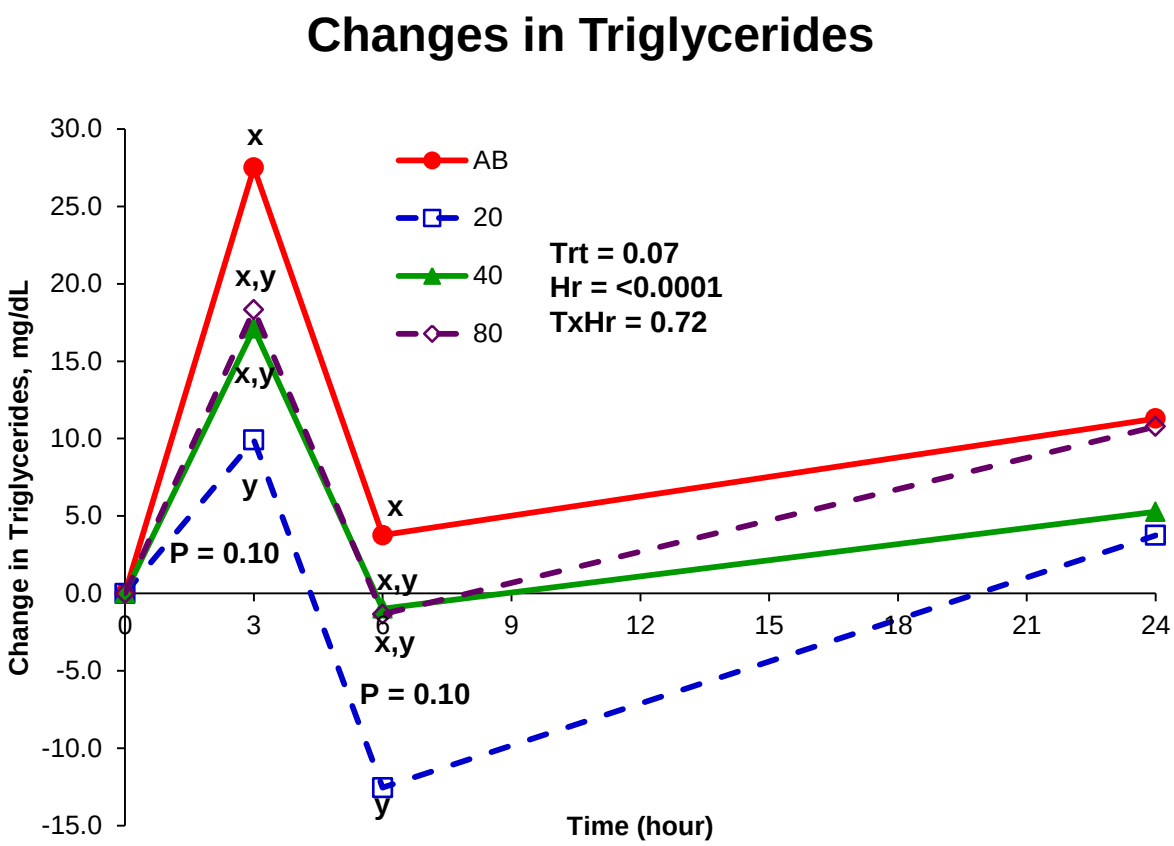


Figure V.8. Effects of low levels of curcumin on changes in triglycerides of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 1). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 20 mg/kg of curcumin powder; ▲ – 20 mg/kg of curcumin powder; ◊ – 80 mg/kg of curcumin powder. There were 6 replications/treatment.

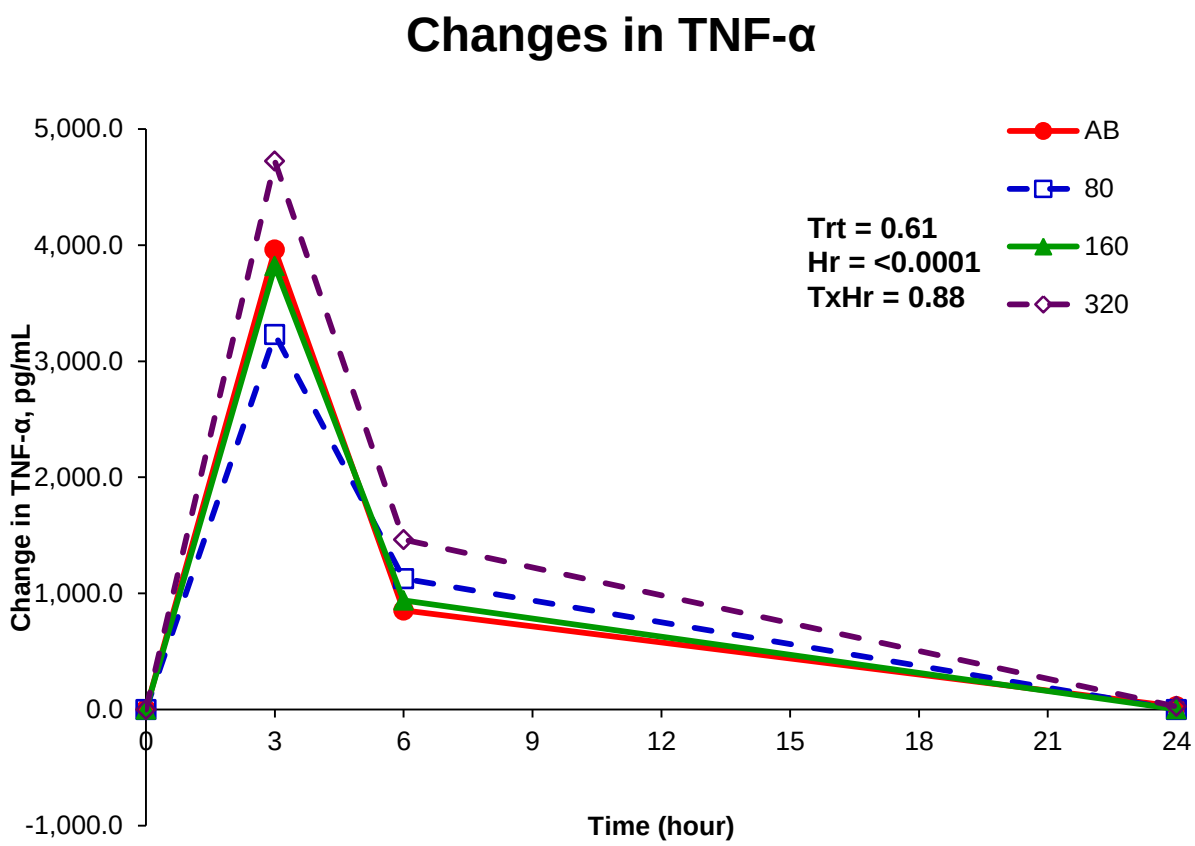


Figure V.9. Effects of high levels of curcumin on changes in tumor necrosis factor-α (TNF-α) of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 2). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 80 mg/kg of curcumin powder; ▲ –160 mg/kg of curcumin powder; ◊ – 320 mg/kg of curcumin powder. There were 7 replications/treatment.

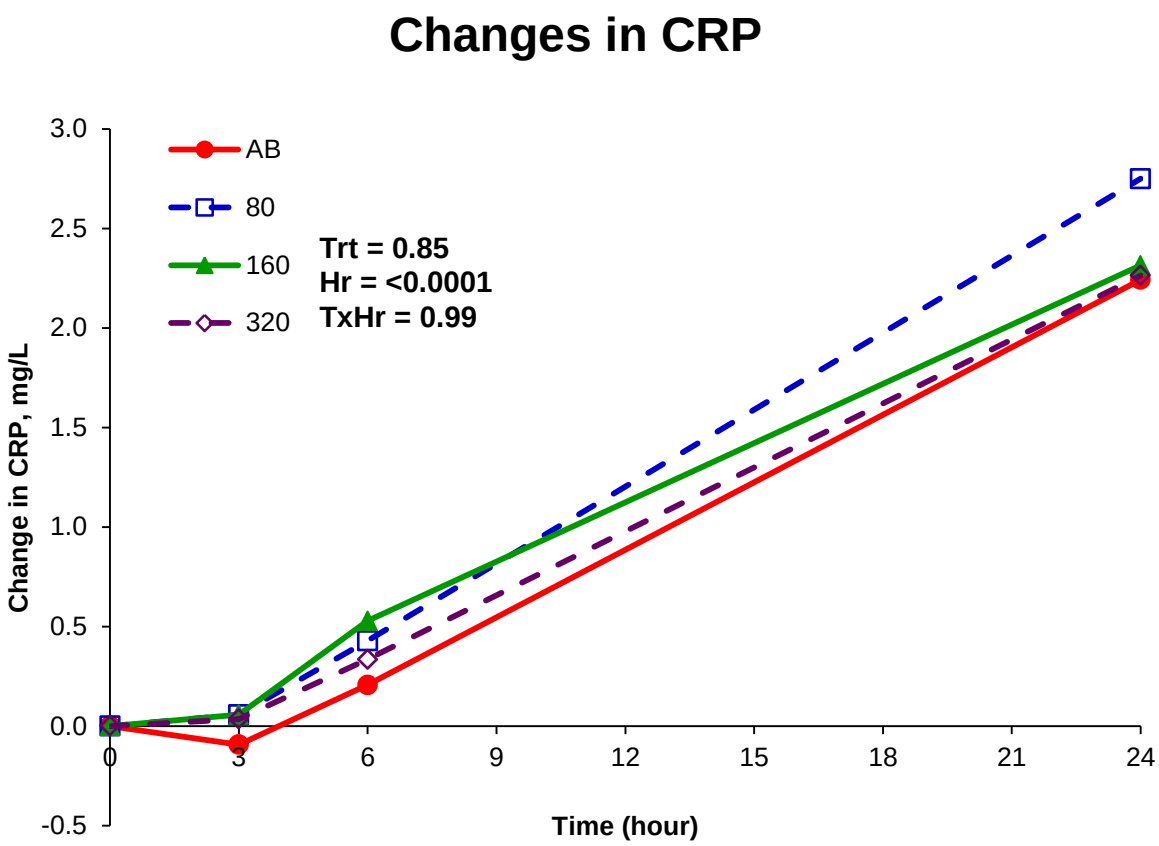


Figure V.10. Effects of high levels of curcumin on changes in C-reactive protein (CRP) of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 2). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 80 mg/kg of curcumin powder; ▲ –160 mg/kg of curcumin powder; ◊ – 320 mg/kg of curcumin powder. There were 7 replications/treatment.

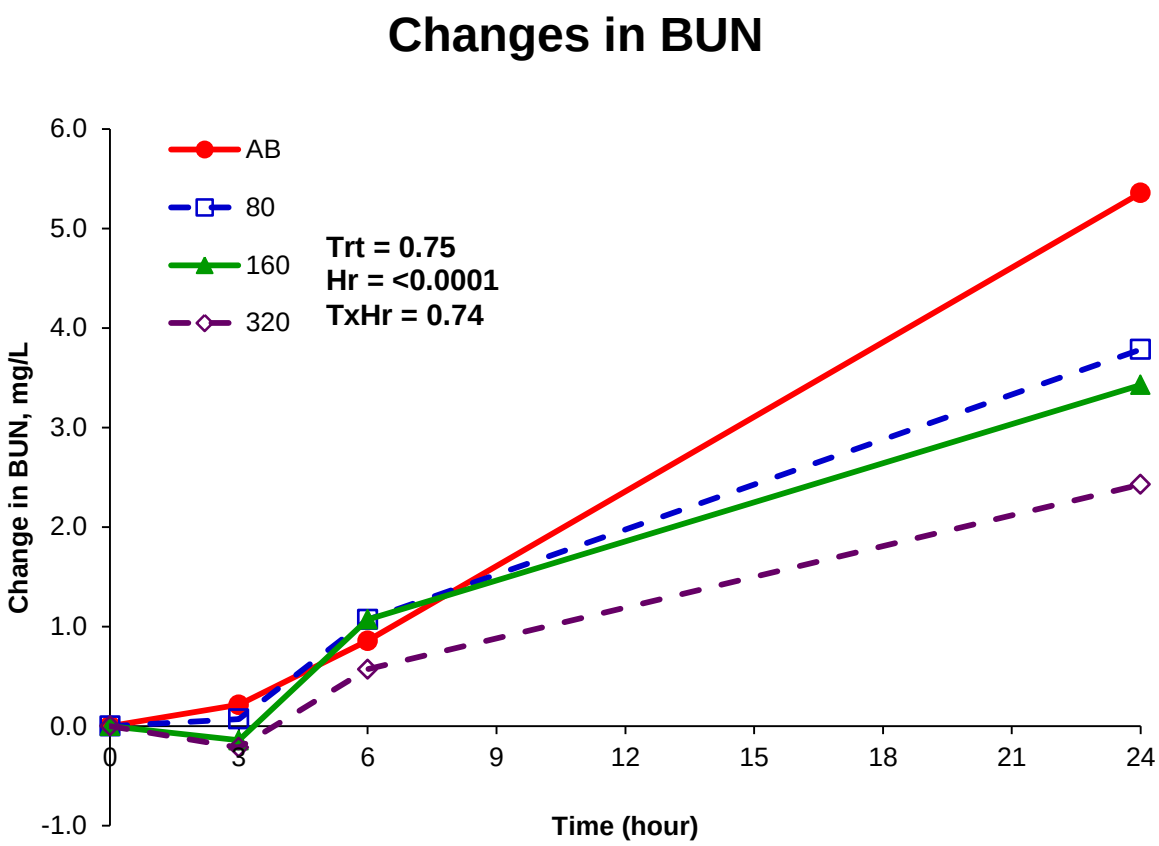


Figure V.11. Effects of high levels of curcumin on changes in blood urea nitrogen (BUN) of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 2). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 80 mg/kg of curcumin powder; ▲ –160 mg/kg of curcumin powder; ◊ – 320 mg/kg of curcumin powder. There were 7 replications/treatment.

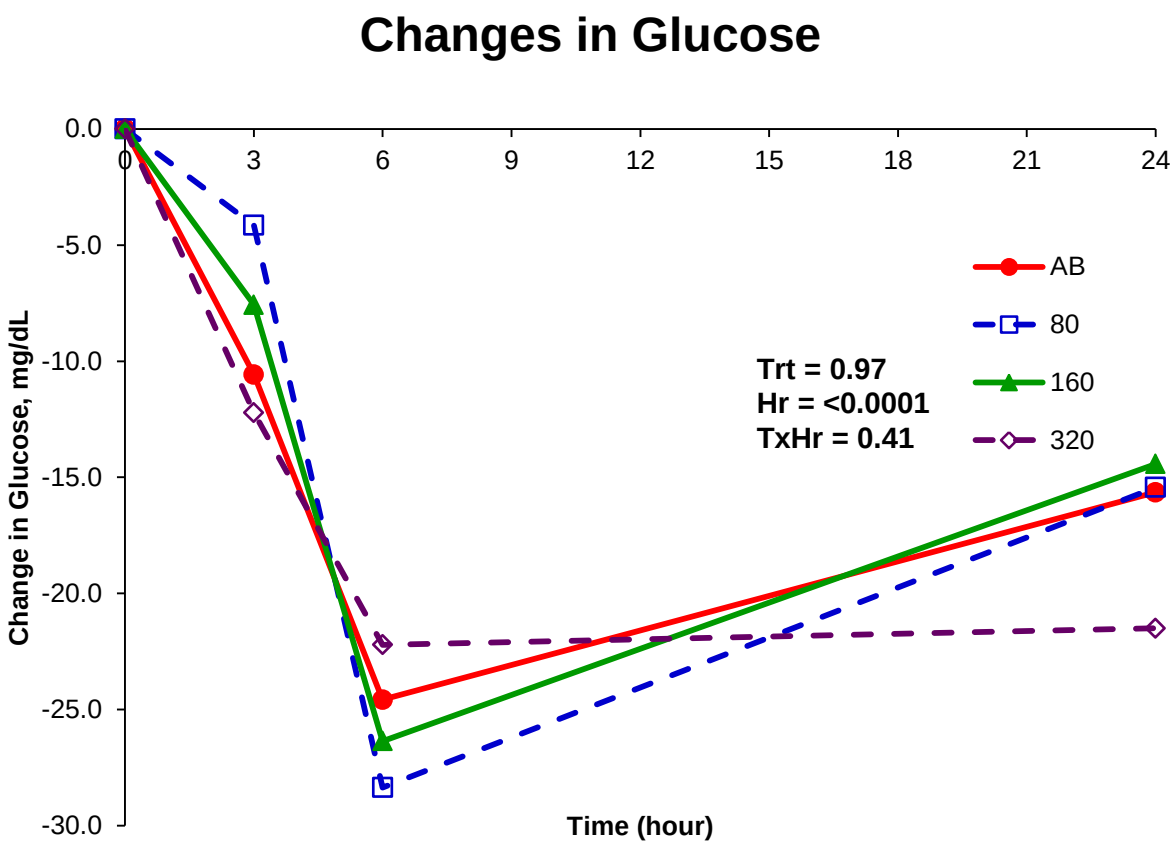


Figure V.12. Effects of high levels of curcumin on changes in glucose of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 2). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 80 mg/kg of curcumin powder; ▲ –160 mg/kg of curcumin powder; ◊ – 320 mg/kg of curcumin powder. There were 7 replications/treatment.

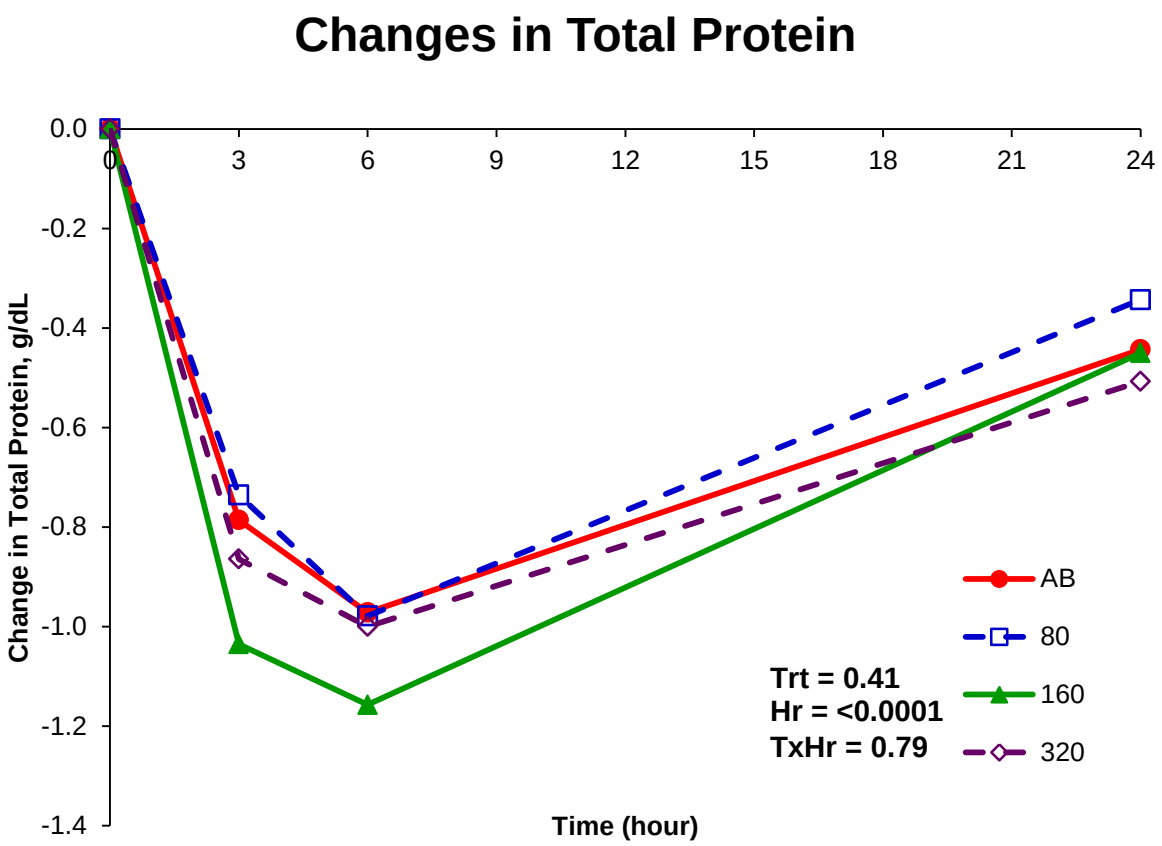


Figure V.13. Effects of high levels of curcumin on changes in total protein of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 2). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 80 mg/kg of curcumin powder; ▲ –160 mg/kg of curcumin powder; ◊ – 320 mg/kg of curcumin powder. There were 7 replications/treatment.

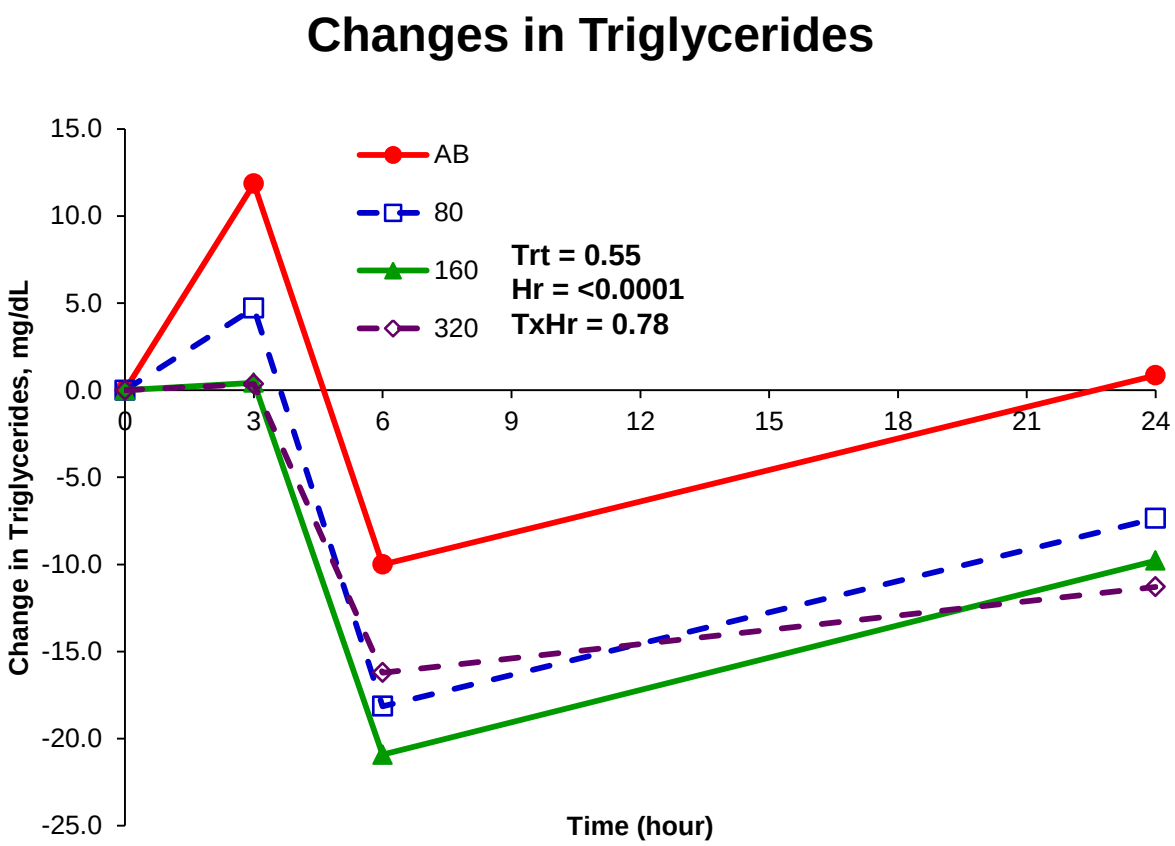


Figure V.14. Effects of high levels of curcumin on changes in triglycerides of nursery pigs during a lipopolysaccharide (LPS) challenge (Exp. 2). The source of LPS was *Escherichia coli* O111:B4. Treatments were the following: ● – antibiotic, 55 mg/kg of carbadox; □ – 80 mg/kg of curcumin powder; ▲ –160 mg/kg of curcumin powder; ◊ – 320 mg/kg of curcumin powder. There were 7 replications/treatment.

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CHAPTER VI

EXPERIMENT IV

A PILOT STUDY: EFFECTS OF INCREASING LEVELS OF CURCUMIN ON GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHER PIGS

M. R. Bible, S. D. Carter, K. F. Coble, and H. J. Kim

Oklahoma State University, Stillwater, OK

ABSTRACT

Curcumin is the major curcuminoid in turmeric. Curcumin has many beneficial properties which include antimicrobial and anti-inflammatory properties. However, curcumin has a very distinct odor and flavor that some may find offensive. Therefore, a pilot study was conducted to study the effects of feeding increasing levels of curcumin to pigs for a total of 168 days on growth performance, carcass traits, and meat quality traits and flavor. A total of 24 crossbred (Duroc x (Landrace x Yorkshire)) pigs (24 kg) were used in a 168-d finishing study. There were 3 replications/treatment and pigs were penned with pen mates from the previous nursery study. Dietary treatments were 1) 44.1 mg/kg of tylosin phosphate (AB), 2) 20 mg/kg of curcumin (20), 3) 40 mg/kg of curcumin (40), and 4) 80 mg/kg of curcumin (80). Pigs were fed a five-phase feeding program that was based on BW. Phases 1, 2, 3, 4, and 5 were fed at d 0-28, 28-42, 42-63, 63-91, and 91-126, respectively. Diets were balanced on SID lysine, calcium, and digestible phosphorus. The SID Lys for each was 1.13%, 0.94%, 0.84%, 0.75%, and 0.66%, respectively. ADG, ADFI, G:F data were calculated from the recording of BW and feed disappearance. At the end of the 126 d, pigs were slaughtered and carcass and meat characteristics were measured. Carcass characteristics measured were: HWC, dressing %, backfat (BF), loin muscle area (LMA), initial fat-free lean (FFL), final FFL, FFL gain, and % FFL. Sensory characteristics for meat quality were juiciness, tenderness, pork flavor and off flavor. For final growth performance, there were no differences ($P > 0.10$) observed for final BW, ADG, ADFI, or G:F. Curcumin consumption

(mg/kg of BW/d) increased (P < 0.0001; linear) with increasing levels of curcumin supplementation. Curcumin had no effect (P > 0.10) on HCW, dressing %, LMA, initial FFL, final FFL, or FFL gain. But, curcumin tended to decrease (P = 0.10; quad) % FFL. There were no effects (P > 0.10) observed for juiciness, tenderness, pork flavor, or off flavor in pigs fed curcumin. In conclusion, when compared to pigs fed an antibiotic, pigs fed curcumin had similar growth performance and carcass and meat characteristics. When pigs were fed curcumin for 168 days, there was no effect on meat quality.

INTRODUCTION

Turmeric, *Curcuma longa* Linn, is spice used in Southeast Asian dishes (Tayyem et al., 2006; Bengmark et al. 2009). Turmeric has been used in these countries since 700 AD for medicinal purposes (Lantz et al., 2005; Tayyem et al., 2006; Rajasekaran, 2011). Currently, turmeric is approved as a food additive, where it is used as a preservative and coloring agent in many foods (Tayyem et al., 2006; Bengmark et al., 2009). There are three major components or curcuminoids in turmeric, which are curcumin, demethoxycurcumin, and bisdemethoxycurmin (Zhang et al., 2010). Giving turmeric its characteristic yellow color and the most active component is curcumin (Lantz et al., 2005; Bengmark et al., 2009). Curcumin has shown to decrease tumor necrosis factor-alpha (TNF-α), interferon-γ (IFN-γ), and cyclooxygenase (COX), and suppress NF-κB activation (Rajasekaran, 2011).

Previous results from Chapter IV showed that 80 mg/kg of curcumin had a similar growth response in nursery pigs vs. pigs fed carbadox. There was also a blunted immune response to an *Escherichia coli* lipopolysaccharide challenge when pigs were fed 80 mg/kg of curcumin. Chapter V studied the effects of increasing levels of curcumin on growth performance and immune response in nursery pigs. Therefore, the effects of long-term consumption of curcumin in pigs were studied. Pigs from Chapter V Exp. 1 were used in this study to determine those long-term effects on growth performance, carcass characteristics, and pork quality and taste.

MATERIALS AND METHODS

Curcuminoid Analysis

The curcumin was analyzed for curcumin, bisdemethoxycurcumin (BDMC), and demethoxycurcumin (DMC). Curcuminoid concentrations were performed using an HPLC by GAAS, Corporation (Tucson, AZ). Briefly, extraction of samples was with a solvent mixture of 80:20 methanol:water and approximately 2 mL of the supernatant was transferred to an amber HPLC vial and injected into the column. The type and size of the column used was a Kinetex C18, 2.6 µ, and 150 x 4.6 mm. All standards used were greater than 91% pure.

Animal Care and Feeding

To study the effects of increasing levels of curcumin on growth performance and carcass characteristics of finishing pigs, a total of 24 crossbred

(Duroc x (Landrace x Yorkshire) pigs were used in a 126-d study. The pigs in this study were from experiment (Exp.) 1 in Chapter V. Two pigs from 12 pens in Exp. 1 were moved to a finisher building. The pigs were allotted by BW and stratified by ancestry and sex within each replication, thus pigs were not placed in a pen with a non-pen mate. All pigs remained on their assigned treatments when moved to the finisher. Therefore, pigs were fed curcumin a total of 168 days, 42 days in the nursery and 126 days in the finisher. The only exception was the antibiotic used was changed to a common antibiotic used in finishing diets. The dietary treatments were: 1) 44.1 mg/kg of tylosin phosphate (AB), 2) 20 mg /kg of curcumin (20), 3) 40 mg/kg of curcumin (40), and 4) 80 mg/kg of curcumin (80). All diets met or exceeded the requirements listed in the Nutrient Requirements for Swine (NRC, 1998). The curcumin powder was purchased from Herbal Extracts Plus (Croydon, PA). Pigs (24 kg) were fed a five-phase feeding program that was based on BW (Tables VI.1-3). Phases 1, 2, 3, 4, and 5 were fed at d 0-28, 28-42, 42-63, 63-91, and 91-126, respectively. Diets were balanced on SID lysine, calcium, and digestible phosphorus. The SID Lys for each was 1.13%, 0.94%, 0.84%, 0.75%, and 0.66%, respectively. Growth performance (ADG, ADFI, G:F) data were calculated from the recording of BW and feed disappearance.

All pigs were cared for and handled following the guidelines established by the Oklahoma State University Institutional Animal Care and Use Committee. Each pen had a stainless steel feeder and a single cup/nipple waterer. Pigs were allowed to consume water and feed *ad libitum*.

Carcass Measurements

When pigs reached the target weight of 122 kg, they were transported to the Robert M. Kerr Food and Agricultural Products Center (FAPC) in Stillwater, OK. Replication 1 and 2 were transported on d 119 and replication 3 was transported on d 126. Before the pigs were transported, they were weighed (slaughter weight). Once at FAPC, the pigs were slaughtered. The pigs were de-haired, eviscerated, and the hot carcass weights (HCW) were recorded. After chilling for 24 hours, other carcass measurements were obtained from the carcass. Backfat (BF) measurements were taken between the 10^{th} and 11^{th} rib. It was measured over the loin directly at ¾ the distance from the midline. Loin muscle area (LMA) was traced on Aquabee® acetate paper and later area was calculated using a grid. The dressing % ((HCW/slaughter BW)*100) was calculated. Initial fat-free lean (FFL; kg) was calculated using the following equation: initial FFL = 0.95 * (-3.65 + (0.418 * initial BW)). The equation for final FFL was: final FFL = 0.95 * (7.231 + (0.437 * HCW) + (18.746 + BF) + (3.877 * LMA)). The FFL gain used was FFL gain = (final FFL – initial FFL) / days on feed. And finally, the % FFL was calculated using the equation: % = (final FFL / HCW) * 100 (NRC, 1998).

Sensory Evaluation

One pig per pen was used to evaluate the effects of curcumin on sensory characteristics of the pork. Pork chops were allowed to unthaw at refrigeration (2-5°C) temperatures. Then, the chops were cooked on an impingement oven

(XLT Ovens, Model 3240TS2, BOFI, Wichita, KS) to an internal temperature of 70°C. After cooking, the chops were cut into 1 cm x 1 cm x 2.54 cm samples. Chop samples were assigned randomly to a sample number. Pork chop chunks were placed into their appropriately labeled plastic cups. The cups were placed in warmers to keep the samples warm.

The sensory panel was composed of six Oklahoma State University personnel. A single tasting session was held. The room where the session was held was a light and temperature controlled room with individual booths. Each booth had a red light that helped avoid any visual bias. Each panelist was supplied with unsalted crackers and distilled, deionized water that were used to cleanse the palate in between each sample. The pork chops were evaluated on initial and sustained juiciness, initial and sustained tenderness, pork flavor, and off flavor. See Table VI.4 for the selection criteria.

Statistical Analysis

All data were analyzed using a randomized complete block design (SAS Institute, version 9.3). Due to unequally spaced levels of curcumin, coefficients were derived using SAS Proc IML. Growth performance, carcass characteristics, and sensory characteristics were analyzed using a GLM procedure. Orthogonal polynomial contrasts (linear and quadratic trends) were used to analyze the effects of increasing levels of curcumin powder, as well as, a non-orthogonal contrast of no curcumin vs. curcumin. Pen served as the experimental unit. The treatment means are presented as least squares means. Differences were considered significant at the $P < 0.05$ level and a trend at $0.05 < P > 0.10$.

RESULTS

Curcuminoid Concentrations

The analyzed concentrations for curcumin, DMC, and BDMC were 58%, 12%, and 2%, respectively. The calculated curcuminoid concentrations for the formulated diets are listed in Table VI.5.

Growth Performance

All data for growth performance are shown in Table VI.6. No differences ($P > 0.10$) were observed for initial BW. Curcumin had no effect ($P > 0.10$) on final body weight. For d 0-28, all pigs fed curcumin gained ($P = 0.05$) more weight compared with pigs fed AB. No other differences ($P > 0.10$) were observed for ADG. Numerically, curcumin increased ADG compared with pigs fed AB for d 0-126. For ADFI and G:F, there were no differences ($P > 0.10$) observed. All pigs consumed approximately the same amount of feed and had similar G:F throughout the 126-d study. As curcumin levels increased in the diet, the amount of curcumin consumed on mg/kg of BW/d basis increased ($P < 0.0001$; linear). The curcumin consumed was 0, 0.34, 0.69, and 1.34 mg/kg of BW/d for AB, 20, 40, and 80, respectively.

Carcass Characteristics

Carcass characteristic data are listed in Table VI.7. For HCW, curcumin had no effect ($P > 0.10$). Numerically, there was an increase in HCW as curcumin increased in the diet. The dressing % was not affected ($P > 0.10$) by

the inclusion of curcumin in the diet. There was no effect (P > 0.10) on feeding curcumin in regards to backfat. No effect (P > 0.10) was noted for LMA, but numerically curcumin increased LMA. No differences were observed for initial or final fat-free lean when curcumin was supplemented to the diet. There was a numerical increase in final FFL as curcumin was added to the diet. Curcumin had no effect (P > 0.10) on FFL gain. However, there was a tendency (P = 0.10; quad) for curcumin to decrease the % FFL.

Sensory Characteristics

Table VI.8 has the sensory characteristics data. Curcumin had no effect (P > 0.10) on initial or sustained juiciness, initial or sustained tenderness, pork flavor, or off flavor. Therefore, the results discussed further will be numerical differences only. As curcumin increased in the diet, the initial and sustained juiciness decreased. Initial and sustained tenderness was decreased as curcumin increased. However, pork flavor was increased with the supplementation of curcumin in the diet. Curcumin did not give the pork an off flavor.

DISCUSSION

The curcumin for this study was labeled as 95% curcumin. After analysis, the curcumin was 58% curcumin, 12% DMC, and 2% BDMC, respectively. Commercially available curcumin is not normally 100% pure. Average curcuminoid concentrations for curcumin are 77%, 17%, and 3% of curcumin, DMC, and BDMC, respectively (Anand et al., 2008). The curcuminoid

concentrations in this study were below the normal commercial standards. The curcumin concentrations were 48% less than the calculated concentrations. Even though the curcumin levels were lower than calculated, growth performance, carcass traits, and meat quality of pigs fed curcumin were similar to pigs fed AB.

There is very little published data on feeding curcumin to swine. Bille et al. (1985) reported a decrease in growth performance when pigs were fed a turmeric oleoresin. A concentration of 1551 mg/kg of BW/d decreased gain and feed efficiency in pigs. Another study by Ilsley et al. (2005) reported no improvement in growth performance in pigs fed 200 mg/kg of curcumin compared to pigs fed a non-antibiotic diet. Pigs fed curcumin in this study had no observable negative effects on growth performance and their ADG was higher when compared to pigs fed antibiotic. Therefore, our results are different than what was reported by Bille et al. (1985) and Ilsley et al. (2005).

Maneewan et al. (2012) reported an increase in nutrient digestibility of crude protein, crude fat, crude fiber, ash, and biological value of protein in pigs fed increasing levels of turmeric. The levels of turmeric were 0%, 0.05%, 0.10%, and 0.20%. The higher levels of turmeric (0.10% and 0.20%) had the highest levels of digested nutrients. However, there were no differences observed on growth performance for pigs fed turmeric when compared to a control with no antibiotics (Maneewan et al., 2012). It is possible the increase in ADG observed in the current experiment is due to an increase in nutrient digestibility. There was a quadratic tendency for curcumin to decrease %FFL.

Previous research in Chapter IV and V reported when nursery pigs were fed curcumin their growth response was similar pigs fed an antibiotic. In this study, pigs fed curcumin performed similar to pigs fed an antibiotic. Curcumin also increased ADG when fed to finishing pigs. Previous research in Chapter IV reported when pigs were fed 80 mg/kg of curcumin, growth performance was similar to pigs fed an antibiotic. Also, in Chapter V, curcumin levels of 20, 40, and 80 mg/kg of curcumin had similar growth performance when compared to an antibiotic.

Currently, there is no cited literature on the effects of curcumin on carcass traits in pigs. However, Emadi and Kermanshahi (2006) reported no effect on liver, pancreas, or spleen weight of chickens fed turmeric. However, turmeric did decrease heart weight and abdominal fat pad weight of broiler chickens. There was no effect on carcass color index when turmeric was fed to chickens (Emadi and Kermanshahi, 2006). Our current study reported no effects of increasing levels of curcumin on HCW, LMA, dressing %, or backfat. However, curcumin tended to decrease % fat-free lean, which is similar to the increase of abdominal fat pad observed in Emadi and Kermanshahi (2006). This differences observed in this study could be due to the final body weight. Pigs fed curcumin were heavier than pigs fed AB and this could have resulted in higher fat deposition.

Even though research has reported a low absorption level of curcumin when consumed orally (Esatbeyoglu et al., 2012), one of the objectives was to study long term effects of curcumin intake on meat taste and quality. This is because turmeric (curcumin) has a bitter, tart taste and a spicy, aromatic aroma.

The bitter taste is more than likely a defense mechanism against herbivores (Esatbeyoglu et al., 2012). Our results report no effect on meat quality or any off flavors.

CONCLUSION

In conclusion, there was no effect on growth performance, carcass characteristics, or meat quality traits in pigs fed curcumin for 168 days compared with pigs fed antibiotic. However, this was just a pilot study and further research should be conducted on the effects of long-term feeding of curcumin in pigs.

Table VI.1 Diet composition of dietary treatments[a] for phases 1 and 2

Dietary Phase	**Phase 1 (20-41 kg)**				**Phase 2 (41-61 kg)**			
Ingredients, %	**AB**	**20**	**40**	**80**	**AB**	**20**	**40**	**80**
Corn	57.44	57.48	57.48	57.48	65.31	65.36	65.36	65.36
Soybean meal	37.30	37.30	37.30	37.30	29.67	29.67	29.67	29.67
Granulated fat	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate	0.75	0.75	0.75	0.75	0.50	0.50	0.50	0.50
Limestone	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[b]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Vitamin premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix[d]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
SelPlex[e]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Tylosin	0.05				0.05			
Curcumin		0.002	0.004	0.008		0.002	0.004	0.008
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis								
ME, kcal/kg	1581	1581	1581	1581	1586	1587	1587	1587
Crude protein, %	22.5	22.5	22.5	22.5	19.5	19.5	19.5	19.5
SID Lysine, %	1.13	1.13	1.13	1.13	0.94	0.94	0.94	0.94
Calcium, %	0.70	0.70	0.70	0.70	0.62	0.62	0.62	0.62
Available phosphorus, %	0.32	0.32	0.32	0.32	0.27	0.27	0.27	0.27

[a]AB = 44.1 mg/kg of tylosin phosphate/kg; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.

[b]Provided 17777 FYT/kg phytase (Ronozyme CT, DSM).

[b]Provided 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.

[c]Provided 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.

[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.

Table VI.2 Diet composition of dietary treatments[a] for phases 3 and 4

Dietary Phase	**Phase 3 (61-82 kg)**				**Phase 4 (82-102 kg)**			
Ingredients, %	**AB**	**20**	**40**	**80**	**AB**	**20**	**40**	**80**
Corn	59.58	69.62	69.62	69.62	73.25	73.29	73.29	73.29
Soybean meal	25.56	25.56	25.56	25.56	22.01	22.01	22.01	22.01
Granulated fat	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Dicalcium phosphate	0.36	0.36	0.36	0.36	0.26	0.26	0.26	0.26
Limestone	1.03	1.03	1.03	1.03	1.02	1.02	1.02	1.02
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Phytase[b]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Vitamin premix[c]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Trace mineral premix[d]	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
SelPlex[e]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Tylosin	0.05				0.05			
Curcumin		0.002	0.004	0.008		0.002	0.004	0.008
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated Analysis								
ME, kcal/kg	1589	1590	1590	1590	1592	1592	1592	1592
Crude protein, %	17.9	17.9	17.9	17.9	16.5	16.5	16.5	16.5
SID Lysine, %	0.84	0.84	0.84	0.84	0.75	0.75	0.75	0.75
Calcium, %	0.57	0.57	0.57	0.57	0.54	0.54	0.54	0.54
Available phosphorus, %	0.23	0.23	0.23	0.23	0.21	0.21	0.21	0.21

[a]AB = 44.1 mg/kg of tylosin phosphate/kg; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.

[b]Provided 17777 FYT/kg phytase (Ronozyme CT, DSM).

[b]Provided 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.

[c]Provided 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.

[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.

Table VI.3 Diet composition of dietary treatments[a] for phase 5

Dietary Phase	**Phase 5 (102-122 kg)**			
Ingredients, %	**AB**	**20**	**40**	**80**
Corn	76.92	76.97	76.97	76.97
Soybean meal	18.42	18.42	18.42	18.42
Granulated fat	3.00	3.00	3.00	3.00
Dicalcium phosphate	0.18	0.18	0.18	0.18
Limestone	1.00	1.00	1.00	1.00
Salt	0.25	0.25	0.25	0.25
Phytase[b]	0.02	0.02	0.02	0.02
Vitamin premix[c]	0.05	0.05	0.05	0.05
Trace mineral premix[d]	0.06	0.06	0.06	0.06
SelPlex[e]	0.05	0.05	0.05	0.05
Tylosin	0.05			
Curcumin		0.002	0.004	0.008
TOTAL	100.00	100.00	100.00	100.00
Calculated Analysis				
ME, kcal/kg	1594	1594	1594	1594
Crude protein, %	15.1	15.1	15.1	15.1
SID Lysine, %	0.66	0.66	0.66	0.66
Calcium, %	0.51	0.51	0.51	0.51
Available phosphorus, %	0.19	0.19	0.19	0.19

[a]AB = 44.1 mg/kg of tylosin phosphate; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.

[b]Provided 17777 FYT/kg phytase (Ronozyme CT, DSM).

[b]Provided 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.

[c]Provided 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.

[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.

Table VI.4 Sensory characteristics ballot for finisher pigs fed increasing levels of curcumin

	Sensory Characteristic			
Scale	**Juiciness**	**Tenderness**	**Pork Flavor**	**Off Flavor**
1	extremely dry	extremely tough	extremely bland	not detectable
2	very dry	very tough	very bland	slightly detectable
3	moderately dry	moderately tough	moderately bland	strong
4	slightly dry	slightly tough	slightly bland	
5	slightly juicy	slightly tender	slightly intense	
6	moderately juicy	moderately tender	moderately intense	
7	very juicy	very tender	very intense	
8	extremely juicy	extremely tender	extremely intense	

Table VI.5. Calculated curcuminoid concentrations of increasing levels of curcumin powder[a] fed to finishing pigs

Curcumin (mg/kg of diet)	Curcuminoid (mg/kg of diet)		
	CUR[b]	DMC[c]	BDMC[d]
20	11.6	2.4	0.41
40	23.2	4.8	0.81
80	46.4	9.6	1.6

[a]Curcumin powder = 57.99% curcumin, 12.02% demethoxycurcumin, and 2.03% bisdemethoxycurcumin
[b]CUR = curcumin
[c]DMC = demethoxycurcumin
[d]BDMC = bisdemethoxycurcumin

Table VI.6. Effects of increasing levels of curcumin powder on growth performance of finisher pigs[a]

	Treatments[b]					P =		
	AB	20	40	80	SE	Lin	Quad	A vs C[c]
BW, kg								
d 0	24.2	23.6	24.1	24.3	0.50	0.65	0.52	0.71
d 28	45.7	46.4	46.9	47.2	0.44	0.05	0.46	0.07
d 42	58.1	60.1	60.2	59.5	0.79	0.40	0.13	0.10
d 63	77.0	79.9	80.1	79.0	0.66	0.16	0.02	0.01
d 91	97.1	100	99.4	98.6	1.83	0.75	0.34	0.31
d 126	116	120	120	117	2.6	0.99	0.23	0.33
ADG, kg/d								
d 0-28	0.77	0.82	0.81	0.82	0.017	0.14	0.21	0.05
d 28-42	0.89	0.98	0.95	0.87	0.048	0.61	0.17	0.42
d 42-63	0.86	0.90	0.90	0.89	0.021	0.46	0.16	0.13
d 63-91	0.80	0.81	0.77	0.79	0.064	0.78	0.89	0.87
d 91-126	0.60	0.64	0.65	0.60	0.048	0.63	0.31	0.70
d 0-126	0.76	0.80	0.79	0.77	0.022	0.93	0.21	0.32
ADFI, kg/d								
d 0-28	1.62	1.64	1.74	1.61	0.058	0.99	0.18	0.52
d 28-42	2.19	2.26	2.09	2.06	0.112	0.30	0.92	0.70
d 42-63	1.84	2.00	1.98	1.87	0.156	0.98	0.43	0.55
d 63-91	2.54	2.56	2.54	2.60	0.112	0.71	0.88	0.84
d 91-126	2.26	2.16	2.26	2.11	0.122	0.48	0.81	0.57
d 0-126	2.08	2.10	2.13	2.05	0.088	0.75	0.61	0.95
G:F								
d 0-28	0.48	0.50	0.47	0.51	0.016	0.34	0.48	0.51
d 28-42	0.41	0.43	0.46	0.43	0.023	0.63	0.20	0.29
d 42-63	0.47	0.45	0.47	0.48	0.034	0.76	0.84	0.96
d 63-91	0.32	0.32	0.30	0.30	0.018	0.48	0.93	0.66
d 91-126	0.27	0.30	0.29	0.27	0.020	0.88	0.35	0.45
d 0-126	0.37	0.38	0.37	0.38	0.013	0.81	0.66	0.51
Curcumin Consumed, mg/kg BW/d								
	0	0.34	0.69	1.34	0.019	<0.0001	0.49	<0.0001

[a]Least squares means for 3 replications/treatment.
[b]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[c]A vs C = antibiotic versus all curcumin treatments.

Table VI.7. Effects of increasing levels of curcumin powder on carcass characteristics of finisher pigs[a]

	Treatments[b]					P =		
	AB	20	40	80	SE	Lin	Quad	A vs C[c]
Initial BW, kg	24.2	23.6	24.1	24.3	0.50	0.65	0.52	0.71
Final BW, kg	116	122	120	117	2.6	0.99	0.23	0.33
HCW, kg	89.3	95.9	91.5	90.7	1.85	0.81	0.16	0.17
Dressing, %	77.2	78.3	76.5	77.6	0.52	0.96	0.64	0.67
Backfat, mm	21.2	22.0	23.1	21.0	0.97	0.83	0.15	0.48
LMA[d], mm^2	5263	5220	4946	5376	193.3	0.73	0.22	0.72
FFL[e], kg								
initial[f]	8.0	7.9	8.0	8.1	0.23	0.81	0.71	0.87
final[g]	47.1	49.4	46.6	48.0	0.83	0.95	0.97	0.38
gain[h]	0.32	0.34	0.32	0.33	0.007	0.96	0.88	0.36
%[i]	52.7	51.6	50.9	53.0	0.82	0.67	0.10	0.42

[a]Least squares means for 3 replications/treatment.
[b]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[c]A vs C = antibiotic versus all curcumin treatments.
[d]LMA = loin muscle area
[e]FFL = fat-free lean.
[f]initial = 0.95 * (-3.65 + (0.418 * initial BW)).
[g]final = 0.95 * (7.231 + (0.437 * HCW) + (18.746 + BF) + (3.877 * LMA)).
[h]gain = (final FFL – initial FFL) / days on feed
[i]% = (final FFL / HCW) * 100

Table VI.8. Effects of increasing levels of curcumin powder on sensory characteristics of finisher pigs[a]

	Treatments[b]					P =		
	AB	20	40	80	SE	Lin	Quad	A vs C[c]
Juiciness[d]								
initial	5.7	5.7	5.8	5.3	0.37	0.91	0.61	0.84
sustained	5.6	5.6	5.6	5.1	0.40	0.86	0.41	0.64
Tenderness[e]								
Initial	6.0	6.0	6.2	5.9	0.19	0.59	0.91	0.94
sustained	5.8	5.8	6.0	5.7	0.15	0.68	1.00	0.84
Pork flavor[f]	6.0	5.6	5.9	5.6	0.26	0.44	0.85	0.45
Off flavor[g]	1.2	1.1	1.1	1.1	0.12	0.65	0.74	1.00

[a]Least squares means for 3 replications/treatment.
[b]AB = antibiotic; 20 = 20 mg/kg curcumin powder; 40 = 40 mg/kg curcumin powder; 80 = 80 mg/kg curcumin powder.
[c]A vs C = antibiotic versus all curcumin treatments.
[d]Juiciness = 1-extremely dry; 2-very dry; 3-mdoerately dry; 4-slightly dry; 5-slightly juicy; 6-moderately juicy; 7-very juicy; 8-extremely juicy.
[e]Tenderness = 1-extremely tough; 2-very tough; 3-moderately tough; 4-slightly tough; 5-slightly tender; 6-moderately tender; 7-very tender; 8-extremely tender.
[f]Pork flavor = 1-extremely bland; 2-very bland; 3-moderately bland; 4-slightly bland; 5-slightly intense; 6-moderately intense; 7-very intense; 8-extremely intense.
[g]Off flavor = 1-not detectable; 2-slightly detectable; 3-strong.

CHAPTER VII

EXPERIMENT V

POTENTIAL FOR INCREASING SOYBEAN MEAL USAGE IN DIETS OF WEANLING PIGS USING CURCUMIN

M. R. Bible, S. D. Carter, H. J. Kim, and K. F. Coble

Oklahoma State University, Stillwater, OK

ABSTRACT

Turmeric's active curcuminoid, curcumin, is known to aid in inflammatory bowel diseases, such as Crohn's disease and ulcerative colitis. Thus, there is the potential for curcumin to alleviate gastrointestinal disturbances caused by feeding high levels of soybean meal (SBM). Therefore, 192 (6.3 kg; 6 reps/trt) crossbred (D x (L x Y)) pigs were used to determine the effects of curcumin supplementation in a 30% SBM-based diet on growth performance, fecal consistency, and cost/kg of gain of nursery pigs. Pigs were weaned at 20 d of age, blocked by BW, stratified by sex and ancestry, and allotted randomly to 4 dietary treatments in a randomized complete block design in a 2 x 2 factorial design. The four treatments consisted of the following: 1) control diet (CNT), 2) control diet + 80 mg/kg of dietary curcumin (CC), 3) SBM-based (30%) diet containing no animal products (SBM), 4) SBM diet + 80 mg/kg of dietary curcumin (SC). Pigs were fed diets in four phases. All diets were balanced on ME, SID Lys, Ca, and available P. Feed disappearance and BW were recorded to calculate ADG (g), ADFI (g), and G:F. Fecal scores were recorded on a pen basis. The effects tested were SBM, curcumin, and SBM x curcumin interaction. For d 0-21, SBM decreased ($P < 0.05$) BW, ADG, ADFI, and G:F. Curcumin tended to increase ($P = 0.09$) BW. Fecal consistency was looser ($P = 0.001$) for pigs fed SBM for d 0-21. For d 0-42, SBM decreased ($P = 0.02$) ADG and tended ($P = 0.06$) to decrease BW, but had no effect ($P > 0.10$) on ADFI or G:F. Even though the SBM diet was the cheapest diet, the pigs fed SBM were the lightest pigs at the end of the experiment. The pigs fed SC were 0.7 kg heavier

than the pigs fed SBM, but 0.4 kg lighter than pigs fed CNT. In conclusion, curcumin supplementation had no effect on fecal consistency, but tended to increase BW and may help mediate some of the digestive disturbances caused by high soybean meal-based diets.

INTRODUCTION

Soybean meal (SBM) is the major protein source used in swine diets in the U.S. (Song et al., 2010). With that being stated, the inclusion of SBM in nursery diets can have detrimental effects. Type III hypersensitivity is observed when feeding high levels of SBM to weaned nursery pigs (Li et al., 1991a). The sensitivity is related to the antigenic proteins that are present in SBM. Glycinin and β-conglycinin are the active proteins that cause the problem (Li et al., 1991b). It also contains enzyme inhibitors called Kunitz trypsin inhibitor (α-conglycinin) and Bowman-Birk trypsin-chymotrypsin inhibitor. During the first month after weaning, more than 80% of deaths observed in nursery pigs are the result of diarrhea and SBM may be a cause of the diarrhea (Dréau and Lallès, 1999).

One way to overcome using high concentrations of SBM in nursery diets is by adding animal proteins. However, animal proteins are expensive. A possible avenue is curcumin supplementation. Turmeric, *Curcuma longa* Linn, is a spice used in Southeast Asian countries (Tayyem et al., 2006; Bengmark et al., 2009). Giving turmeric its characteristic yellow color and the most active component is curcumin (Lantz et al., 2005; Bengmark et al., 2009). Curcumin has been shown to have anti-inflammatory effects on gastrointestinal diseases, such as ulcerative

colitis and Crohn's disease. It is believed this occurs by reducing the pro-inflammatory cytokines (Rajasekaran, 2011). Curcumin has the potential to alleviate gastrointestinal disturbances caused by feeding high levels of SBM.

It is hypothesized that the addition of curcumin to diets high in SBM will decrease cost/gain and pigs will perform similar to conventional nursery diets. Therefore, the objective of the study was to determine the effects of growth performance on pigs fed high SBM-based diets supplemented with curcumin, as well as, to determine the cost per gain.

MATERIALS AND METHODS

A total of 192 Duroc x (Landrace x Yorkshire) nursery pigs (~20 days of age) were used to study the effects of feeding curcumin (Herbal Extracts Plus, Croydon, PA) to nursery pigs fed a 30% SBM-based diet in a 42-d study. Nursery pigs were blocked by ancestry, sex, and body weight and allotted randomly to four dietary treatments. Initial body weight was 6.3 kg. The four treatments consisted of the following: 1) control diet (CNT), 2) control diet + 80 mg/kg of curcumin powder (CC), 3) SBM-based (30%) diet containing no animal products (SBM), 4) SBM diet + 80 mg/kg of curcumin powder (SC). Pigs were fed a four-phase feeding program (Tables VII.1-4). All diets met or exceeded the requirements listed in the Nutrient Requirements for Swine (NRC, 1998). Phase 1 diet is the most complex diet with multiple protein sources. De Rouchey et al. (2010) recommended that SBM be fed between the levels of 12-15% of the diet for Phase 1 due to the allergic reaction the weanling pigs will have to certain proteins in the soybean meal. Phase 2 diets are similar to Phase 1, but less

complex. The amount of SBM in the diet can be as high as 20%. The Phase 3 diet resembles more of a corn-soybean meal-based diet with a SBM range between 26-28%. Phase 4 diet consists of a corn-soybean meal-based diet containing over 30% SBM (DeRouchey et al., 2010). The levels of SBM used in the CNT and CC diets were 15.00, 20.00, and 26.32% for phase 1, 2, and 3, respectively. Due to phase 4 containing over 30% SBM, there were only 2 treatment diets, control and control + 80 mg/kg of curcumin. All diets were balanced on metabolizable energy (ME), SID lysine, calcium, and available phosphorus. Phases 1, 2, 3, and 4, were fed at d 0-7, 7-14, 14-21, and 21-42, respectively. The SID lysine for each phase was 1.54%, 1.51%, 1.31%, and 1.25%, respectively. Body weights and feed disappearance were recorded weekly to calculate ADG, ADFI, and G:F. The feed cost of each dietary phase ($/kg), cost per pig ($/pig), and cost per gain per pig ($/gn/pig) were calculated in U.S. dollars. Prices were obtained from Oklahoma State University's feed mill in January 2013 with the exception of the curcumin. Curcumin price was obtained from Herbal Extracts Plus. Also, fecal scores were recorded daily for the first 21 days of the experiment using the scoring system described by Johnston et al. (2001). Fecal scores were recorded on a pen basis.

Pigs were housed in an environmentally-controlled building similar to a commercial setting. Each pen was equipped with a single cup/nipple waterer and a five-hole stainless steel feeder. Pigs were allowed to consume water and feed *ad libitum*. There were 8 pigs per pen with 6 replications per treatment.

Pigs were handled and cared for following the guidelines established by the Oklahoma State University Institutional Animal Care and Use Committee.

The curcumin was analyzed for curcumin, bisdemethoxycurcumin, and demethoxycurcumin. Curcuminoid concentrations were performed using an HPLC by GAAS, Corporation (Tucson, AZ). Briefly, extraction of samples was with a solvent mixture of 80:20 methanol:water and approximately 2 mL of the supernatant was transferred to an amber HPLC vial and injected into the column. The type and size of the column used was a Kinetex C18, 2.6 µ, and 150 x 4.6 mm. All standards used were greater than 91% pure.

Data were analyzed as a randomized complete block design in a 2 x 2 factorial (SAS Institute, version 9.3). The model included treatment, replication, and treatment x replication (error). The effects of soybean meal, curcumin, and soybean meal x curcumin interaction were evaluated. Pen served as the experimental unit. Treatment means are presented as least squares means. Differences were considered significant at the $P < 0.05$ level and a trend at $0.05 < P > 0.10$.

RESULTS

The results for the curcumin powder were 58, 12, and 2% of curcumin (CUR), demethoxycurcumin (DMC), and bisdemethoxycurcumin (BDMC), respectively. The concentrations of curcumin for the dietary treatments were 0, 26.8, 0, and 29.3 mg/kg of diet for CNT, CC, SBM, and SC, respectively.

All performance data (ADG, ADFI, G:F, and BW) are presented in Table VII.6. Pigs fed 30% SBM had a decrease in ADG ($P < 0.0001$), ADFI ($P =$

0.008), and G:F (P = 0.001) when compared with pigs fed low SBM levels for d 0-7. No effects (P > 0.10) were observed for CUR or SBM x CUR interaction for ADG, ADFI, or G:F.

For d 7-14, pigs fed low concentrations of SBM had a higher ADG (P < 0.0001) and G:F (P = 0.001) compared with pigs fed 30% SBM. Pigs fed 30% SBM had a numerical (P = 0.11) decrease in feed/day. There was a tendency (P = 0.10) for a SBM x CUR interaction. No other differences (P > 0.010) were observed for ADG, ADFI, or G:F.

There was no effect (P > 0.01) of 30% SBM on ADG for d 14-21. However, CUR numerically (P = 0.11) increased ADG. No effects of SBM or CUR were observed (P > 0.10) for ADFI or G:F for d 14-21. No SBM x CUR interactions (P > 0.10) were observed.

For d 0-21, pigs fed 30% SBM had lower ADG (P = 0.001) compared with pigs fed lower concentrations of SBM. During d 0-21, high inclusion levels of SBM decreased (P = 0.05) ADFI. Due to lower ADG and ADFI, pigs fed SBM had a lower G:F (P = 0.005) than pigs fed the lower levels of SBM. The inclusion of CUR had no effects (P > 0.10) on ADG, ADFI, or G:F. No soybean meal x curcumin interactions (P > 0.10) were observed. Therefore, the d 21 body weights of pigs fed 30% SBM were lower (P = 0.001) than pigs not fed 30% SBM. There was a trend (P = 0.09) for pigs that consumed CUR to have higher body weights compared to those that did not consume CUR.

During the last 3 weeks (d 21-42) of the nursery, there were no effects (P > 0.10) of SBM, CUR, or their interaction on ADG of nursery pigs. There was a tendency (P = 0.09) for pigs fed CUR to have an increase in feed intake per day. However, there were no effects (P > 0.10) of SBM or a SBM x CUR interaction for ADFI. A tendency (P = 0.07) was observed where pigs fed CUR had a lower G:F than pigs not fed CUR. There was also a tendency (P = 0.09) for there to be a SBM x CUR interaction for ADFI. No differences (P < 0.10) of SBM were observed for ADG, ADFI, or G:F.

For d 0-42, pigs consuming lower levels of SBM gained more weight (P = 0.02) than those consuming 30% SBM. Curcumin inclusion did not affect (P > 0.10) weight gain for d 0-42. Pigs consuming CUR tended (P = 0.09) to consume more feed from d 0-42 than pigs not fed CUR. The level of SBM had no effect (P > 0.10) on ADFI for d 0-42. There were no differences (P > 0.10) observed for G:F for d 0-42. Due to the effect of high SBM levels on ADG, pigs fed 30% SBM tended (P = 0.06) to be lighter at d 42 than pigs fed the gradual increase of SBM. Curcumin intake had no effect (P > 0.10) on d 42 body weights. No interactions (P > 0.10) between SBM and CUR were present for ADG or G:F for d 0-42 or BW on d 42. However, there was a tendency (P = 0.09) for a SBM x CUR interaction for ADFI, where pigs fed 30% SBM had a lower feed intake in contrast to pigs fed SC.

All fecal score are presented in Table VIII.7. When analyzing fecal consistency, there was a tendency for SBM to increase fecal scores for d 0-7 (P = 0.06) and d 7-14 (P = 0.08), and numerically (P = 0.11) increase fecal scores

for d 14-21. For d 0-21, pigs fed 30% SBM were looser (P = 0.001) than pigs fed lower concentrations of SBM. The addition of curcumin to the nursery diets had no effect (P > 0.10) on fecal consistency and there was no SBM x CUR interaction (P > 0.10).

DISCUSSION

Soybean meal is a common protein source in swine diets (Song et al., 2010; Taliercio and Kim, 2013). Taliercio and Kim (2013) reported in 2010 over 24 million metric tons of SBM went to the animal industry to be used as a feed ingredient. With that being stated, newly weaned pigs have a transient local hypersensitivity to proteins present in soybean meal. However, after approximately 10 days of exposure to soybean meal, the pig becomes orally tolerant to the proteins. The response is believed to be mostly due to the proteins glycinin and β-conglycinin (Engle, 1994; Jones et al., 2010). Pigs will have a decrease in growth performance during the hypersensitivity period. Many changes occur in the gastrointestinal tract of the pig during this time. A few changes occurring are an increase in immature enterocytes, villous atrophy, increase in incidence of diarrhea, and decreased absorption capability. These changes contribute to post-weaning lag and susceptibility to *E. coli* and *Rotavirus* (Engle, 1994).

To help the pig overcome the hypersensitivity, high nutrient dense diets are fed to weanling pigs for 14 days. The amount of recommended soybean meal present in these diets can range from 15-22.5%. However, the diets must contain plasma proteins (Friesen et. al, 1993; Jones et al., 2010) and other

animal proteins (Jones et al., 2010). The animal proteins (fishmeal, spray-dried plasma, and spray-dried blood cells) utilized in this study are known to increase performance by increasing feed intake (Jones et al., 2010). Nursery pigs will also perform better if the initial diets (first 2 weeks) contain protein in the form of milk protein (Walker et. al, 1986). This coincides with the results observed in this study. When the pigs were fed low levels of SBM with animal proteins, there was an increase in growth performance. Song et al. (2010) reported that when weanling pigs were fed diets with no SBM, their gain was higher and fecal consistency drier than pigs fed SBM. Even though no differences were observed for the later part of the experiment, the differences observed for the first 14 days carried over until the end of the experiment. Jones et al. (2010) reported similar results as this study. They saw a depression in growth performance and daily gain due to a 40% inclusion rate of SBM (Jones et al., 2010). The depression in growth was not as drastic as this study. That is probably contributed to the initial 7-d acclimation period in which animal products were part of the diet. Jones et al. (2010) also reported similar results in improved performance when animal proteins (fishmeal and dried porcine solubles) were fed, just like the current study.

Previous research at Oklahoma State University has found that feeding nursery pigs a diet that contained 30% SBM resulted in a marked reduction in growth. When compared to a normal nursery diet containing low levels of SBM and animal protein sources, pigs fed 30% SBM were 0.5, 0.7, 1.1, and 1.8 kg lighter after 7, 14, 21 and 42 days in the nursery. Also, the pigs fed the control

diet gained more per day and had a higher gain:feed ratio compared with pigs fed higher levels of SBM (M. R. Bible, unpublished data). The current study has similar results where pigs fed SBM were 0.3, 0.8, 0.7, and 1.2 kg lighter after 7, 14, 21, and 42 days, respectively.

The inclusion of SBM in the diet has been shown to reduce villi height in the jejunum (Dréau and Lallès, 1999). With that being stated, the hypersensitivity that SBM causes initiates inflammation in the intestine and immature enterocytes. It is suggested curcumin can help treat digestive disturbances, such as Crohn's disease, irritable bowel syndrome, ulcerative colitis, and bacterial diseases. The molecular mechanisms behind helping alleviate the gastrointestinal disturbances is by decreasing the activation of pro-inflammatory cytokines, such as tumor necrosis factor-α (TNF-α) and interleukin-1β (IL-1β). Curcumin also helps regulate the expression of the inflammatory mediators, cyclooxygenase-2 (COX-2) and prostaglandin E2 (PGE2; Rajasekaran, 2011). During an *Escherichia coli* lipopolysaccharide challenge, pigs fed curcumin had a decrease in TNF-α in Chapters IV and V. Therefore, curcumin has the potential to alleviate the inflammatory response that comes with the transient hypersensitivity from SBM. To date, there is no other research published about feeding curcumin to pigs consuming high levels of soybean meal. There is little published research on feeding curcumin to pigs. Chapters IV and V reported similar growth performance in pigs fed curcumin compared to pigs fed an antibiotic. The addition of curcumin to the 30% SBM diet did improve

final BW by 3%, ADG by 5%, and ADFI by 11%. Thus, the increase in growth performance could be due to the effects curcumin has on inflammation.

The curcumin concentration used for this experiment was determined from previous research in Chapters IV. Pigs fed SC diet has a similar growth performance as pigs fed curcumin in Chapters IV and V. Also, pigs fed curcumin had a more blunted response to an *Escherichia coli* lipopolysaccharide challenge, when compared to pigs fed antibiotics. Most commercially available curcumin is not pure curcumin. It is, on average, 77% curcumin, 17% DMC, and 3% BDMC (Anand et al., 2008). The curcumin purchased for this study was labeled as 95% curcumin. However, after analysis of the curcumin powder, it was 58%, 12% DMC, and 2% BDMC. Thus, the curcumin did not meet the average commercial standards for curcumin concentrations.

Liu et al, (2013b) reported that 10 mg/kg of turmeric oleoresin alleviated some of the digestive disturbances of an experimentally infected *E. coli* challenge. The fecal score and frequency of diarrhea for pigs fed turmeric were reduced compared to pigs fed a control diet (Liu et al., 2013b). However, we did not observe these same results. In fact, curcumin supplementation had no effect on fecal consistency. In our study, soybean did have an effect on fecal consistency. Pigs fed high levels of soybean had looser stools than pigs not fed high levels of soybean meal.

The cost/pig and cost/gain/pig are in Table VII.8. For d 0-21, the SBM diet was the cheapest on a cost/kg basis and the CC diet was the most expensive.

The CNT and SC diets were intermediate in cost/kg. The SBM diet was cheaper compared to the CNT and SC for cost/pig followed by the CC diet. However, the cost/gain/pig for CNT, SBM, and SC diets were similar with the CC diet being more expensive. For d 0-42, the SBM diet was the cheapest diet on cost/kg. The CC diet was the most expensive. On a cost/pig basis, the SC, CC, and CNT diets were more expensive compared to the SBM diet. The cost/gain/pig for the CNT and SBM diets were similar with the addition of curcumin increasing the cost/gain/pig. The SBM diet was the cheapest diet on a cost and cost per pig basis, as well as, having a similar cost as the CNT diet for cost/gain/pig; however, it should be noted that the pigs fed SBM were the lightest set of pigs at the end of this 42-d study. The pigs fed SBM were 1.2 kg lighter than the pigs fed the CNT. The pigs fed SC were 0.6 kg heavier than the pigs fed SBM. This lighter BW will result in more days in the finisher.

CONCLUSION

In conclusion, curcumin supplementation had no effect on fecal consistency, but tended to increase BW and may help mediate some of the digestive disturbances caused by high levels of soybean meal. Further research should be conducted to study different levels of curcumin to provide the optimum level for nursery pigs fed high levels of soybean meal.

Table VII.1 Diet composition of phase 1 diets

	% in diet			
Ingredients	**CNT[a]**	**CC[a]**	**SBM[a]**	**SC[a]**
Corn	31.30	31.29	20.66	20.66
Soybean meal, dehulled	15.00	15.00	30.00	30.00
Whey, dried	25.00	25.00	25.00	25.00
Lactose	7.00	7.00	7.00	7.00
Plasma, spray-dried	6.00	6.00	-	-
Fishmeal, menhaden	6.00	6.00	-	-
Soy protein concentrate	2.21	2.21	6.99	6.99
Granulated fat	4.00	4.00	5.45	5.45
L-lysine HCl	0.17	0.17	0.26	0.26
DL-methionine	0.18	0.18	0.25	0.25
L-threonine	0.07	0.07	0.11	0.11
Dicalcium phosphate	0.67	0.67	1.85	1.85
Limestone	0.45	0.45	0.47	0.47
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	1.00	1.00	1.00
Curcumin powder	-	0.008	-	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	3497	3497	3498	3498
Crude protein, %	22.93	22.92	23.96	23.96
SID Lysine, %	1.54	1.54	1.54	1.54
Calcium, %	0.89	0.89	0.89	0.89
Available phosphorus, %	0.59	0.59	0.59	0.59

[a]CNT = control diet; CC = control diet + 80 mg/kg curcumin powder; SBM = 30% soybean meal diet; SC = 30% soybean meal diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table VII.2 Diet composition of phase 2 diets

	% in diet			
Feedstuffs	**CNT[a]**	**CC[a]**	**SBM[a]**	**SC[a]**
Corn	37.29	37.28	30.16	30.15
Soybean meal, dehulled	20.00	20.00	30.00	30.00
Whey, dried	25.00	25.00	25.00	25.00
Plasma, spray-dried	2.50	2.50	-	-
Blood cells, spray-dried	1.25	1.25	-	-
Fish meal, menhaden	4.00	4.00	-	-
Soy protein concentrate	2.12	2.12	5.18	5.18
Granulated fat	4.00	4.00	4.95	4.95
L-lysine HCl	0.22	0.22	0.29	0.29
DL-methionine	0.21	0.21	0.23	0.23
L-threonine	0.10	0.10	0.11	0.11
Dicalcium phosphate	0.93	0.93	1.64	1.64
Limestone	0.44	0.44	0.50	0.50
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	1.00	1.00	1.00
Curcumin powder	-	0.008	-	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	3478	3477	3477	3477
Crude protein, %	22.97	22.97	23.58	23.58
SID Lysine, %	1.51	1.51	1.51	1.51
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.55	0.55	0.55	0.55

[a]CNT = control diet; CC = control diet + 80 mg/kg curcumin powder; SBM = 30% soybean meal diet; SC = 30% soybean meal diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table VII.3 Diet composition of phase 3 diets

	% in diet			
Ingredients	**CNT[a]**	**CC[a]**	**SBM[a]**	**SC[a]**
Corn	52.82	52.81	50.10	50.09
Soybean meal, dehulled	26.32	26.32	30.00	30.00
Whey, dried	10.00	10.00	10.00	10.00
Blood cells, spray-dried	1.25	1.25	-	-
Fishmeal, menhaden	2.00	2.00	-	-
Soy protein concentrate	-	-	1.50	1.50
Granulated fat	3.00	3.00	3.40	3.40
L-lysine HCl	0.27	0.27	0.32	0.32
DL-methionine	0.17	0.17	0.16	0.16
L-threonine	0.12	0.12	0.11	0.11
Dicalcium phosphate	1.39	1.39	1.67	1.67
Limestone	0.72	0.72	0.79	0.79
Salt	0.50	0.50	0.50	0.50
Zinc oxide	0.29	0.29	0.29	0.29
Vitamin premix[b]	0.05	0.05	0.05	0.05
Trace mineral premix[c]	0.06	0.06	0.06	0.06
SelPlex[d]	0.05	0.05	0.05	0.05
Mecadox[e]	1.00	1.00	1.00	1.00
Curcumin powder	-	0.008	-	0.008
TOTAL	100.000	100.000	100.000	100.000
Calculated Analysis				
ME, kcal/kg	3420	3420	3419	3419
Crude protein, %	20.94	20.94	21.06	21.06
SID Lysine, %	1.31	1.31	1.31	1.31
Calcium, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.45	0.45	0.45	0.45

[a]CNT = control diet; CC = control diet + 80 mg/kg curcumin powder; SBM = 30% soybean meal diet; SC = 30% soybean meal diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table VII.4 Diet composition of phase 4 diets

Ingredients	% in diet	
	CNT[a]	CC[a]
Corn	58.26	58.26
Soybean meal, dehulled	34.30	34.30
Granulated fat	3.00	3.00
L-lysine HCl	0.25	0.25
DL-methionine	0.11	0.11
L-threonine	0.09	0.09
Dicalcium phosphate	1.58	1.58
Limestone	0.74	0.74
Salt	0.50	0.50
Vitamin premix[b]	0.05	0.05
Trace mineral premix[c]	0.06	0.06
SelPlex[d]	0.05	0.05
Mecadox[e]	1.00	1.00
Curcumin powder	-	0.008
TOTAL	100.000	100.000
ME, kcal/kg	3608	3607
Crude protein, %	21.50	21.50
SID Lysine, %	1.25	1.25
Calcium, %	0.75	0.75
Available phosphorus, %	0.37	0.37

CNT = control diet; CC = control diet + 80 mg/kg curcumin powder.
[b]Vitamin mix provided per kg diet: 11,023 IU of vitamin A, 1,653 IU of vitamin D, 71.6 IU of vitamin E, 4.41 mg of vitamin K, 9.92 mg of riboflavin, 49.6 mg of niacin, 45.2 mg of pantothenic acid, 0.22 mg of biotin, 408 mg vitamin B_{12}, 1.21 mg of folic acid, 1.37 mg of pyridoxine, and 2.2 mg of thiamin.
[c]Mineral mix provided per kg diet: 0.24 mg of calcium, 9.96 mg of copper, 0.36 mg of iodine, 90.7 mg of iron, 31.8 mg of manganese, and 99 mg of zinc.
[d]Selplex provided per kg of diet: 0.3 mg of organic selenium.
[e]Carbadox provided at 55 mg/kg of diet.

Table VII.5 Fecal scoring system[a]

Scoring System
1 – Hard
2 – Normal
3 – Soft, partially formed
4 – Loose
5 – Watery

[a]Johnston et al., 2001

Table VII.6. Effects of feeding 80 mg/kg of curcumin powder with a 30% soybean meal inclusion on growth performance of nursery pigs[a]

	Treatments[b]					P =		
	CNT	CC	SBM	SC	SE	SBM[c]	CUR[c]	SxC[c]
BW, kg								
d 0	6.3	6.3	6.4	6.3	0.04	0.14	0.67	0.96
d 7	7.1	7.0	6.8	6.8	0.06	0.001	0.51	0.82
d 14	8.8	8.8	8.0	8.2	0.20	<0.0001	0.50	0.25
d 21	11.4	11.6	10.7	11.1	0.16	0.001	0.09	0.37
d 42	23.4	23.7	22.2	23.0	0.43	0.06	0.30	0.64
ADG, g								
d 0-7	110	106	60	58	9.1	<0.0001	0.74	0.87
d 7-14	235	234	162	194	10.1	<0.0001	0.15	0.13
d 14-21	372	402	378	401	15.5	0.87	0.11	0.83
d 0-21	240	248	200	218	8.0	0.001	0.12	0.53
d 21-42	584	591	564	583	14.8	0.36	0.38	0.69
d 0-42	408	416	377	397	9.8	0.02	0.19	0.57
ADFI, g								
d 0-7	175	185	152	168	6.6	0.008	0.07	0.57
d 7-14	338	348	313	322	14.8	0.11	0.53	0.95
d 14-21	612	635	575	610	26.8	0.26	0.30	0.83
d 0-21	375	386	345	364	12.3	0.05	0.25	0.78
d 21-42	1013	1028	937	1051	35.7	0.47	0.09	0.19
d 0-42	687	698	630	697	21.8	0.20	0.09	0.21
G:F								
d 0-7	0.639	0.575	0.392	0.339	0.0572	0.001	0.33	0.93
d 7-14	0.700	0.678	0.523	0.602	0.0287	0.001	0.33	0.10
d 14-21	0.615	0.644	0.656	0.665	0.0255	0.24	0.47	0.71
d 0-21	0.645	0.646	0.582	0.607	0.0156	0.005	0.42	0.46
d 21-42	0.577	0.576	0.603	0.558	0.0119	0.76	0.07	0.09
d 0-42	0.593	0.596	0.601	0.572	0.0105	0.44	0.22	0.15

[a]Least squares means for 6 pens/treatment.

[b]CNT = control diet; CC = control diet + 80 mg/kg curcumin; SBM = 30% soybean meal diet; SC = 30% soybean meal diet + 80 mg/kg curcumin powder.

[c]SBM = soybean meal effect; CUR = curcumin effect; SxC = soybean meal x curcumin interaction.

Table VII.7. Effects of feeding 80 mg/kg of curcumin powder with a 30% soybean meal inclusion on fecal consistency of nursery pigs[a]

	Treatments[b]					P =		
	CNT	CC	SBM	SC	SE	SBM[c]	CUR[c]	SxC[c]
Fecal Score[d]								
d 0-7	2.7	2.8	3.0	3.1	0.14	0.06	0.47	0.87
d 7-14	3.1	3.0	3.4	3.2	0.14	0.08	0.39	0.63
d 14-21	2.6	2.6	2.8	2.8	0.12	0.11	0.97	0.80
d 0-21	2.8	2.8	3.1	3.0	0.06	0.001	0.94	0.66

[a]Least squares means for 6 pens/treatment.
[b]CNT = control diet; CC = control diet + 80 mg/kg curcumin powder; SBM = 30% soybean meal diet; SC = 30% soybean meal diet + 80 mg/kg curcumin powder.
[c]SBM = soybean meal effect; CUR = curcumin effect; SxC = soybean meal x curcumin interaction.
[d]Fecal score: 1 = hard; 2 = normal; 3 = soft, partially formed; 4 = loose; 5 = watery (Johnston et al., 2001).

Table VII.8. Effects of feeding 80 mg/kg of curcumin powder with a 30% soybean meal inclusion on cost/pig and cost/gain/pig of nursery pigs[a]

	Treatments[b]			
	CNT	**CC**	**SBM**	**SC**
D 0-7				
cost, $/kg	1.26	1.31	0.98	1.02
FI, kg[c]	1.23	1.30	1.06	1.18
cost/pig, $/kg	1.54	1.69	1.04	1.20
Gn[4], kg	0.77	0.74	0.42	0.41
cost/gn/pig, $/gn/pig	2.01	2.28	2.48	2.97
D 7-14				
cost, $/kg	1.04	1.08	0.90	0.94
FI, kg[c]	2.37	2.44	2.19	2.25
cost/pig, $/kg	2.46	2.64	1.97	2.13
Gn[4], kg	1.65	1.64	1.13	1.36
cost/gn/pig, $/gn/pig	1.50	1.61	1.74	1.57
D 14-21				
cost, $/kg	0.69	0.74	0.66	0.71
FI, kg[c]	2.60	2.81	2.65	2.81
cost/pig, $/kg	1.80	2.07	1.75	1.99
Gn[4], kg	2.60	2.81	2.65	2.81
cost/gn/pig, $/gn/pig	0.69	0.74	0.66	0.71
D 0-21				
cost, $/kg	0.94	0.98	0.81	0.85
FI, kg[c]	6.20	6.55	5.90	6.24
cost/pig, $/kg	5.81	6.40	4.77	5.32
Gn[4], kg	5.04	5.21	4.20	4.58
cost/gn/pig, $/gn/pig	1.15	1.23	1.14	1.16
D 21-42				
cost, $/kg	0.52	0.56	0.52	0.56
FI, kg[c]	21.3	21.6	19.7	22.1
cost/pig, $/kg	11.05	12.18	10.22	12.45
Gn[4], kg	5.96	6.11	5.54	5.94
cost/gn/pig, $/gn/pig	1.85	1.99	1.84	2.09
D 0-42				
cost, $/kg	0.61	0.66	0.59	0.63
FI, kg[c]	27.5	28.1	25.6	28.3
cost/pig, $/kg	16.86	18.58	14.99	17.77
Gn[4], kg	17.1	17.5	15.8	16.7
cost/gn/pig, $/gn/pig	0.98	1.06	0.95	1.07

[a]cost = U.S. dollars

[b]CNT = control diet; CC = control diet + 80 mg/kg curcumin powder; SBM = 30% soybean meal diet; SC = 30% soybean meal diet + 80 mg/kg curcumin powder.

[c]FI = total feed intake

[d]Gn = total gain

CHAPTER VIII

SUMMARY

Post-weanling lag is the most stressful time for a nursery pig. Numerous changes occur within the body of the pig, such as, a decrease in gastrointestinal enzymes, hormonal changes, intestinal microbial changes, and a decrease in villi. These changes are due to the drastic change in diet, milk to dry feed. There is also a decrease in feed intake in association with post-weaning lag. All of these changes produce a decrease in growth and performance in nursery pigs. A common method to help alleviate the stressors of post-weaning lag is high nutrient dense diets that contain subtherapeutic antibiotics. However, with the growing concern of antibiotic-resistant bacteria, the use of antibiotics in feed is slowly starting to decrease. A possible replacement for subtherapeutic antibiotics is plant extracts. Turmeric is an herbaceous spice that contains an active component called curcumin. Turmeric and curcumin have been shown to have antimicrobial and anti-inflammatory properties. Thus, the effects of turmeric and curcumin on growth performance and immune response in swine were studied.

GROWTH PERFORMANCE

BW, ADG, and ADFI, and linearly increased G:F when compared to a control diet containing no antibiotics or zinc. Pigs fed 4 g/kg of turmeric had the greatest ADG, ADFI, and G:F. The concentrations of curcumin present in the turmeric fed were 47, 94, and 189 mg/kg for 2, 4, and 8 g/kg of turmeric. Turmeric and curcumin intake (mg/kg of BW/d) increased linearly in Exp. I.

Figure VIII.1 shows the relationship between growth performance and curcumin in the diet for Exp. I. The control diet (0 intake) in this experiment contained no antibiotics or zinc. Based on the results there is a strong quadratic increase growth performance with increasing curcumin supplementation (R^2 > 0.975). Therefore, the level of curcumin to maximize growth performance of nursery pigs in Exp. 1 was between 47 and 94 mg/kg.

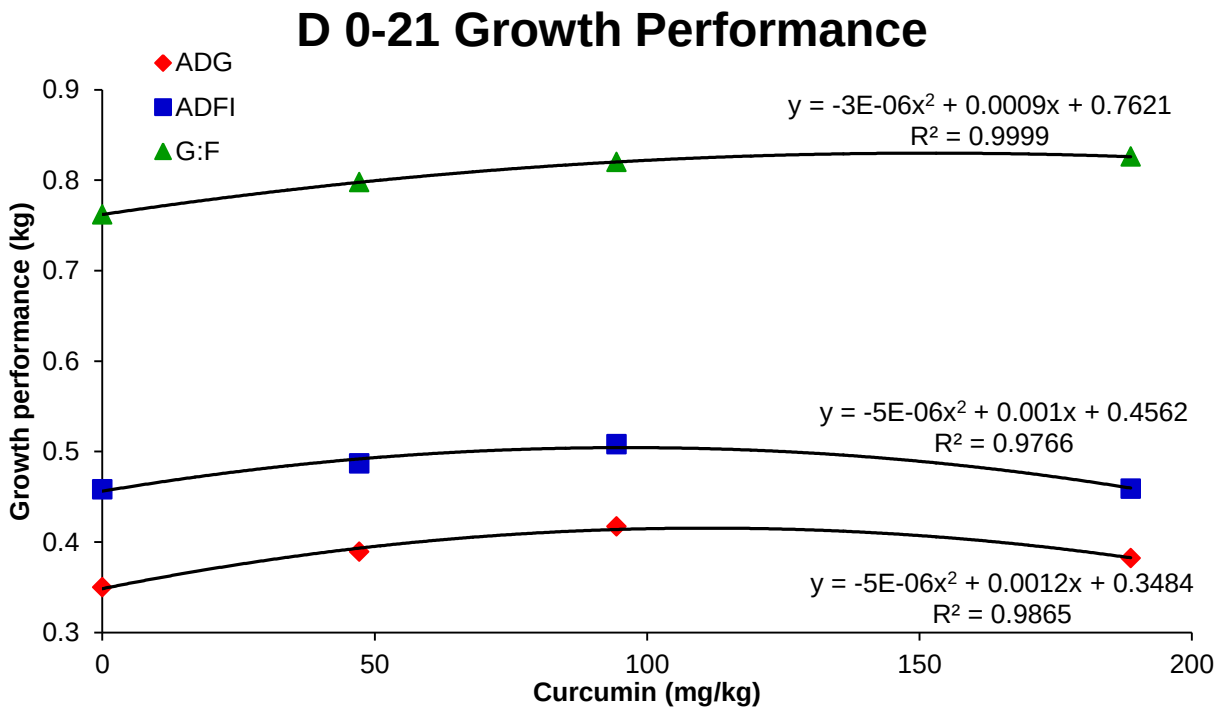

Figure VIII.1. Relationship between curcumin concentrations in the diet and growth performance for Exp. 1

In Exp. II, pigs fed 46 mg/kg of curcumin had similar final BW, ADG, ADFI, and G:F as pigs fed 55 mg/kg of carbadox (antibiotic). However, pigs fed 2 g/kg of turmeric with 25 mg/kg of curcumin had a lower final BW, ADG, ADFI, and G:F. The amount of curcumin consumed on a mg/kg of BW/d basis for the pigs fed curcumin was 1.69. Pigs fed the turmeric consumed 0.86 mg/kg of BW/d of curcumin. The growth performance results observed in pigs fed the turmeric in Exp. II were not similar to the growth performance for pigs fed turmeric in Exp. I. This is probably due to the lower curcumin concentrations in the turmeric in Exp. II.

Exp. III was a two-part study where different levels of curcumin were compared to pigs fed carbadox. In the first part of Exp. III, pigs were fed lower levels of curcumin. The levels fed were 12, 23, and 46 mg/kg of diet. These levels of curcumin had no effect on final BW or ADG when compared to carbadox. However, there was a quadratic response for ADFI and G:F, where pigs fed curcumin consumed less feed/day and had a higher G:F. The 23 mg/kg of curcumin was the most similar in growth performance when compared to the antibiotic. The curcumin intake levels increased linearly with the intake levels for 12, 23, and 46 mg/kg of curcumin being 0.76, 1.43, and 3.01 mg/kg of BW/d, respectively.

The second part of Exp. III studied the effects of higher levels of curcumin compared to carbadox. In this part of the study, the curcumin levels were 46, 93, and 186 mg/kg of diet. There was no effect of curcumin on ADFI for this portion of Exp. III. However, increasing levels of curcumin decreased final BW, ADG,

and G:F when compared to the antibiotic. Curcumin levels of 92.8 mg/kg had similar growth performance as the antibiotic. The curcumin intake increased linearly. Curcumin intake was 2.86, 5.53, and 11.6 mg/kg of BW/d for the levels of 46.4, 92.8, and 185.6 mg/kg of diet, respectively.

Figure VIII.2 shows the relationship between growth performance for d 0-21 and curcumin in the diet for Exp. II and III. Based on the results there is an increasing cubic relationship between ADG and curcumin supplementation (R^2 = 0.75), ADFI and curcumin supplementation (R^2 = 0.71), and G:F and curcumin levels (R^2= 0.82). Therefore, to have maximum growth performance, the level of curcumin was between 46 and 93 mg/kg of curcumin in the diet.

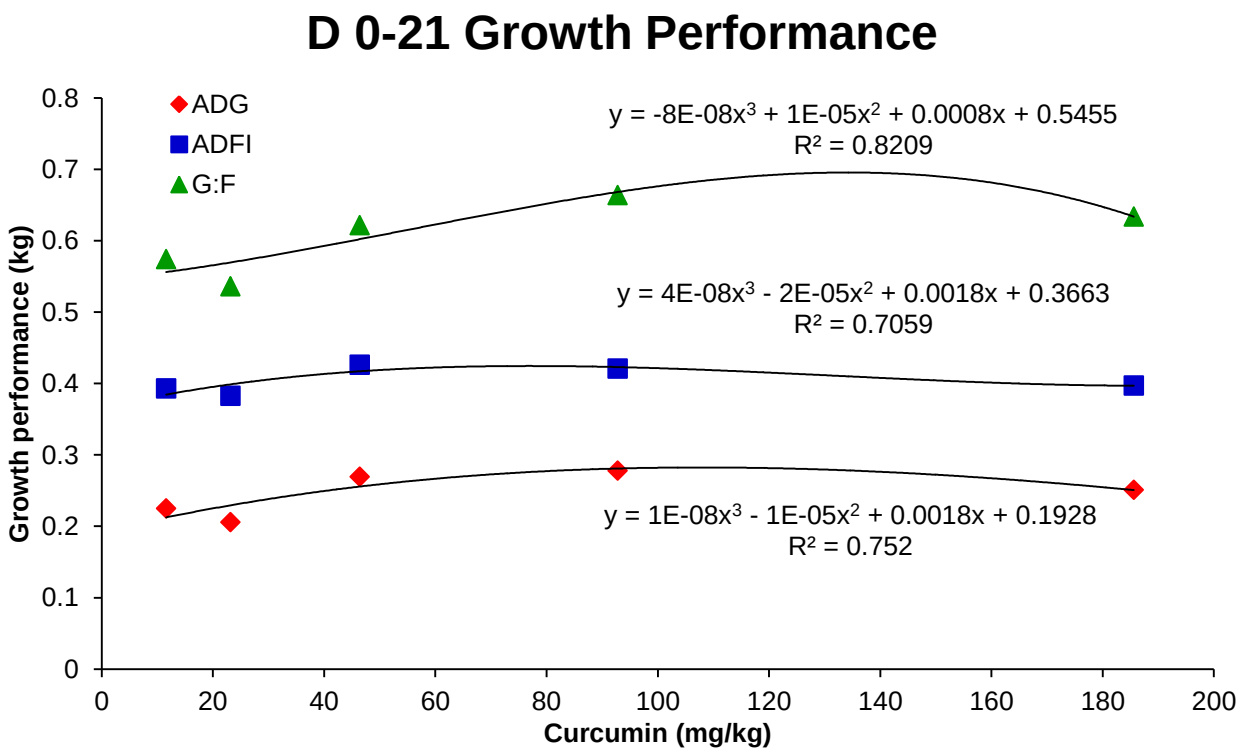

Figure VIII.2. Relationship between growth performance for d 0-21 and curcumin concentrations in the diet for Exp. II and III.

Figure VIII.3 shows the association between growth performance for d 0-42 and curcumin in the diet for Exp. II and III. Based on the results there is an increasing quadratic relationship between G:F and curcumin supplementation (R^2 = 0.71) and a decreasing quadratic response for ADFI and curcumin supplementation (R^2 = 0.78). There is a strong decreasing quadratic relationship for ADG and curcumin levels (R^2= 0.98) for d 0-42. To maximize growth performance of nursery pigs at d 0-42, the best level of curcumin was between 46 and 93 mg/kg.

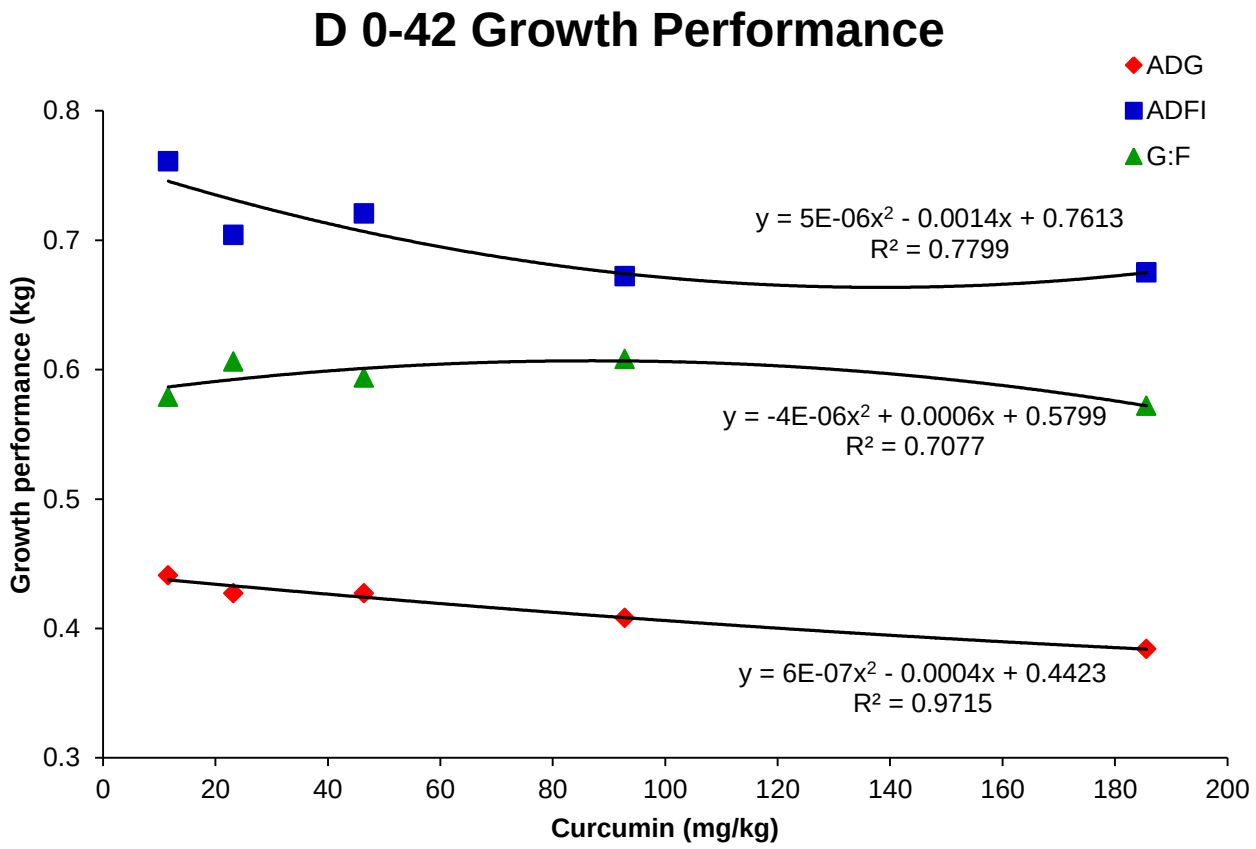

Figure VIII.3. Relationship between growth performance for d 0-42 and curcumin concentrations in the diet for Exp. II and III.

Exp. IV studied the effects of long-term feeding of curcumin in finisher pigs at the levels of 12, 23, and 46 mg/kg of the diet compared to an antibiotic. When

pigs were fed these levels of curcumin for 168 days, there were no differences observed for final BW, ADG, ADFI, or G:F. The curcumin intake increased linearly where curcumin intake levels were 0.34, 0.69, and 1.34 mg/kg of BW/d for the levels of 12, 23, ad 46 mg/kg of the diet. Feeding curcumin at these levels also had no effect on the carcass traits, hot carcass weight, dressing %, backfat, loin muscle area, initial fat-free lean, final fat-free lean, fat-free lean gain. There was a quadratic trend for % fat-free lean where pigs fed curcumin had a lower % fat-free lean. This could be attributed to the numerically higher final BW. Also, in Exp. IV., meat quality characteristics were studied. Curcumin had on effect on initial or sustained juiciness, initial or sustained tenderness, pork flavor, or off flavor.

The final experiment, Exp. V, studied the effects of growth performance and fecal consistency of 46 mg/kg of curcumin in high soybean meal-based diets in nursery pigs. Curcumin tended to lower d 21 BW, but there was no effect of curcumin on final BW. Curcumin numerically increased d 0-21 ADG, ADFI, and G:F and 0-42 ADG and ADFI. Curcumin had no effect on fecal consistency during d 0-21. However, 30% soybean meal decreased d 21 BW and tended to decrease final BW. The high soybean meal-based diets decreased ADG, ADFI, and G:F for d 0-21 and decreased final ADG. The 30% soybean meal also decreased fecal consistency for d 0-21.

IMMUNE RESPONSE

To study the effects of curcumin on the innate immune response, *Escherichia coli* O111:B4 lipopolysaccharide at 25 µg/kg of BW was injected intraperitoneally in nursery pigs at d 21 in Exp. I, II, and III. This model is a proven model to initiate an immune response. In every experiment, rectal temperatures and TNF-α concentrations peaked at h 3 PI, but returned to normal by 24 h PI. The concentrations of CRP and BUN peaked at hr 24 PI. Glucose levels decreased until h 6 PI, and started to return to normal by h 24 PI. Triglyceride concentrations increased at h 3 PI, decreased at h 6 PI, and started to return to normal by h 24 PI. Total protein tended to decrease until h 6 PI and slowly returned to normal by h 24 PI, but total protein levels were somewhat variable during the LPS challenge.

In Exp. I, turmeric numerically decreased rectal temperature and TNF-α concentrations at h 3 PI. Also, at hr 3 PI, turmeric had a lower increase in TNF-α compared to the control with no antibiotics, and pigs fed 47 mg/kg of curcumin had the smallest change in TNF-α.

Figures VIII.4 shows the relationship between curcumin in the diet (mg/kg) and rectal temperature expressed as a percent of the control diet (no antibiotics or zinc) for Exp. I. All levels of curcumin had a lower rectal temperature at h 3 PI. This is the time point when rectal temperatures peaked; therefore, curcumin helped control the fever from the LPS challenge.

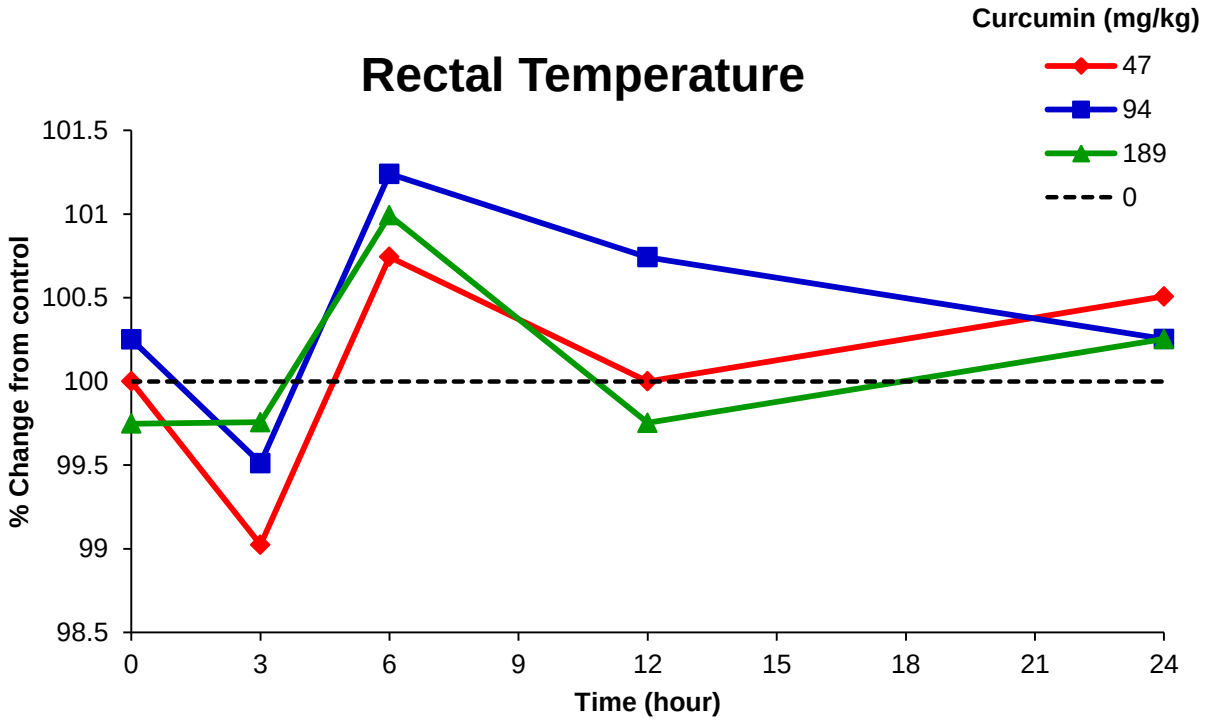

Figure VIII.4. Relationship between curcumin in the diet (mg/kg) and rectal temperature expressed as a percent of the control (no antibiotic or zinc) during a LPS challenge for Exp. 1.

The relationship between TNF-α and curcumin concentration (mg/kg of the diet) is shown in Figure VIII.5 for Exp. I. During the entire LPS challenge, TNF-α concentrations were lower in pigs fed curcumin compared to pigs fed the control. Curcumin aided in alleviating some of the inflammation that is associated with a LPS challenge by decreasing rectal temperature at h 3 PI.

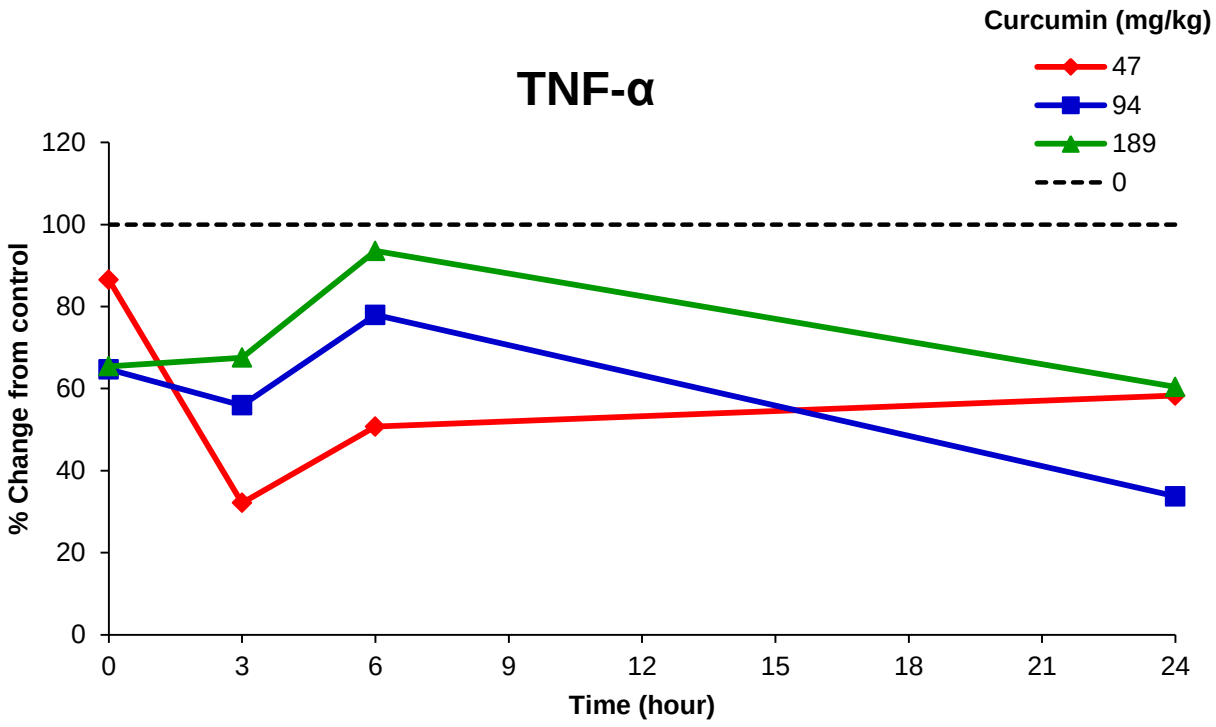

Figure VIII.5. Relationship between curcumin in the diet (mg/kg) and TNF-α as expressed as a percent of the control (no antibiotic or zinc) during a LPS challenge for Exp. 1.

For Exp. II, curcumin or turmeric had no effect on rectal temperatures during any time point of the LPS challenge. Curcumin at 46.4 mg/kg of the diet decreased TNF-α concentrations and had the least change in TNF-α at h 3 PI, but turmeric (curcumin at 25.0 mg/kg of the diet) had no effect on TNF-α.

There was no effect of curcumin on rectal temperatures during the LPS challenge for study 1 of Exp. III. Curcumin numerically decreased TNF-α at h 3 PI. The curcumin concentration of 11.6 mg/kg of the diet had the lowest concentration of TNF-α at h 3 PI.

For study 2 of Exp. III., curcumin linearly decreased rectal temperatures at h 3 PI. The level of 185.6 mg/kg of the diet had the lowest numerical rectal temperature at h 3 PI. The TNF-α concentrations at h 3 PI were not affected by

curcumin concentration. The curcumin at 46.4 mg/kg of the diet had the lowest numerical TNF-α concentration at h 3 PI. When looking at the change in TNF-α, curcumin had less of a change when compared to the antibiotic with 47.2 mg/kg of the diet having the smallest change in TNF-α at h 3 PI.

The relationship between rectal temperature expressed as a percent of the control diet (antibiotic) and curcumin levels in the diet (mg/kg) for Exp. II and III are shown in Figure VIII.6. Curcumin levels at 23, 93, 186 mg/kg had slightly higher rectal temperatures when compared to the antibiotic at h 3 PI for Exp. II and III.

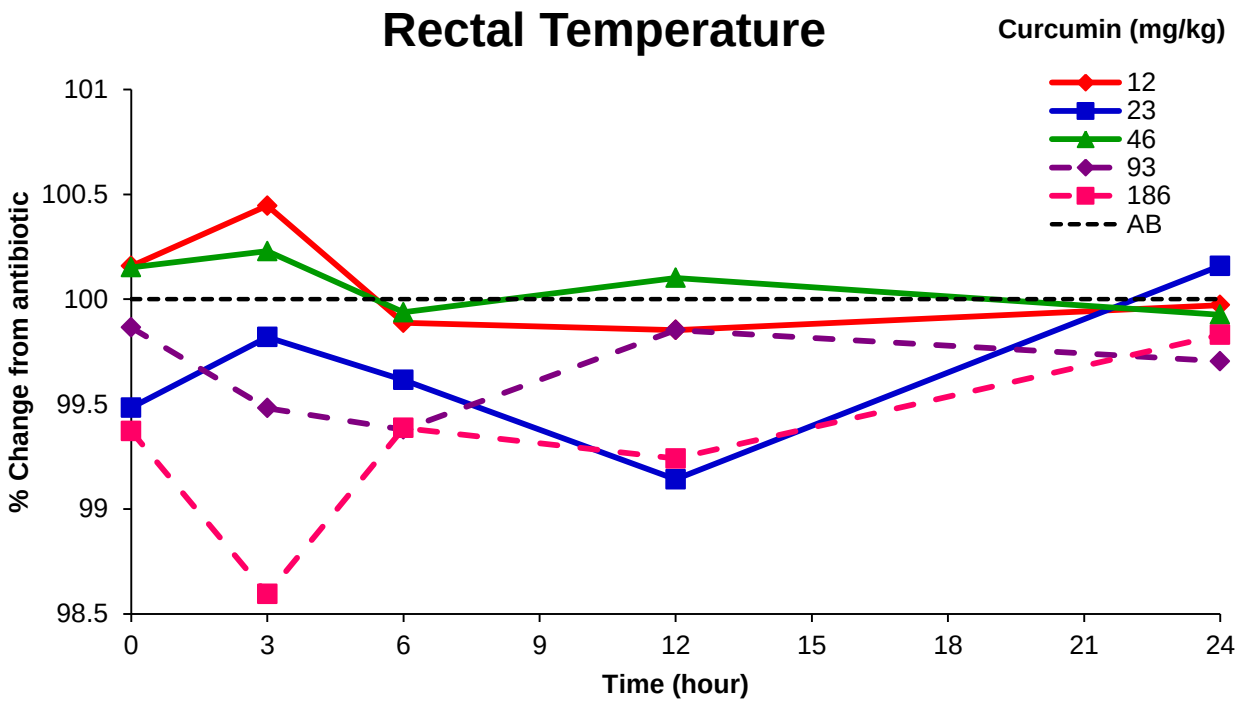

Figure VIII.6. Relationship between curcumin in the diet (mg/kg) and rectal temperature expressed as a percent of the control (antibiotic) during a LPS challenge for Exp. II and III.

Figure VIII.7 shows the relationship between curcumin levels in the diet and TNF-α expressed as a percent of the antibiotic. At h 3 PI, 12 and 23 mg/kg

of curcumin were higher compared to the antibiotic. The curcumin levels at 46, 93, and 186 mg/kg were lower at h 3 PI.

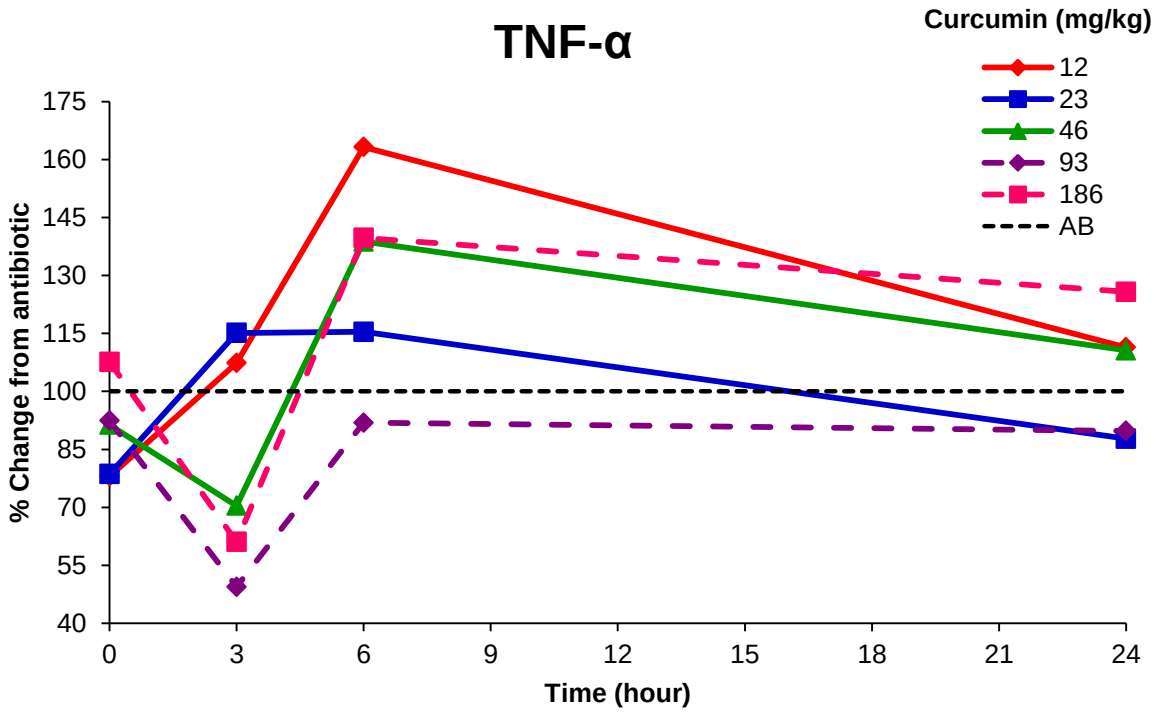

Figure VIII.7. Relationship between curcumin in the diet (mg/kg) and TNF-α expressed as a percent of the control (antibiotic) during a LPS challenge for Exp. II and III.

CONCLUSION

In the end, the source of the curcumin is important, whether it be from curcumin powder or from turmeric. As mentioned earlier, the concentration of curcumin in turmeric is dependent on many different variables, such as climate and soil acidity. In our case, the turmeric fed in Exp. II did not improve growth performance or help blunt the response of a LPS challenge when compared to a control diet containing no antibiotics. However, the turmeric fed in Exp. I did enhance growth performance and blunt the immune response. These differences could be attributed to the curcumin concentrations in the turmeric.

The curcumin concentration for the 2 g/kg of turmeric in Exp. I was 47 mg/kg and the curcumin concentration for the 2 g/kg of turmeric in Exp. II was 25.0 mg/kg. Thus, curcumin levels in turmeric are important when feeding turmeric to swine to enhance growth performance and immunomodulation of the immune system. Just because a product is labeled as a certain percent does not mean it is correct. The curcumin fed in these experiments was labeled as 95% curcumin, but after analysis it was 58% curcumin. Therefore, before feeding curcumin or turmeric to pigs, the concentration of curcumin should be determined.

Figure VIII.8 shows the comparison of Exp. I turmeric vs Exp. II and III curcumin in regards to the relationship of curcumin levels in the diet (mg/kg) and ADG for d 0-21. Curcumin concentrations in the diet are highly quadratically correlated to ADG (R^2 = 0.99), whereas, curcumin levels increase so does ADG. There is a quadratic increase for the relationship of curcumin levels and ADG studied in Exp. II and III (R^2 = 0.75). Therefore, for maximum ADG, the level of curcumin that should be supplemented in the diets of nursery pigs is 46 and 94 mg/kg. The contrast between Exp. 1 turmeric and Exp. II and III curcumin in regards to the association of curcumin levels and TNF-α at h 3 PI are shown in Figure VIII.9. There is a quadratic response, where as curcumin levels increase in the diet, TNF-α decreases for Exp. 1 (R^2 = 0.63) and Exp. II and III (R^2 = 0.92). In order to reduce inflammation the most during an immune response, the levels of curcumin to be fed to nursery pigs is around 95 mg/kg.

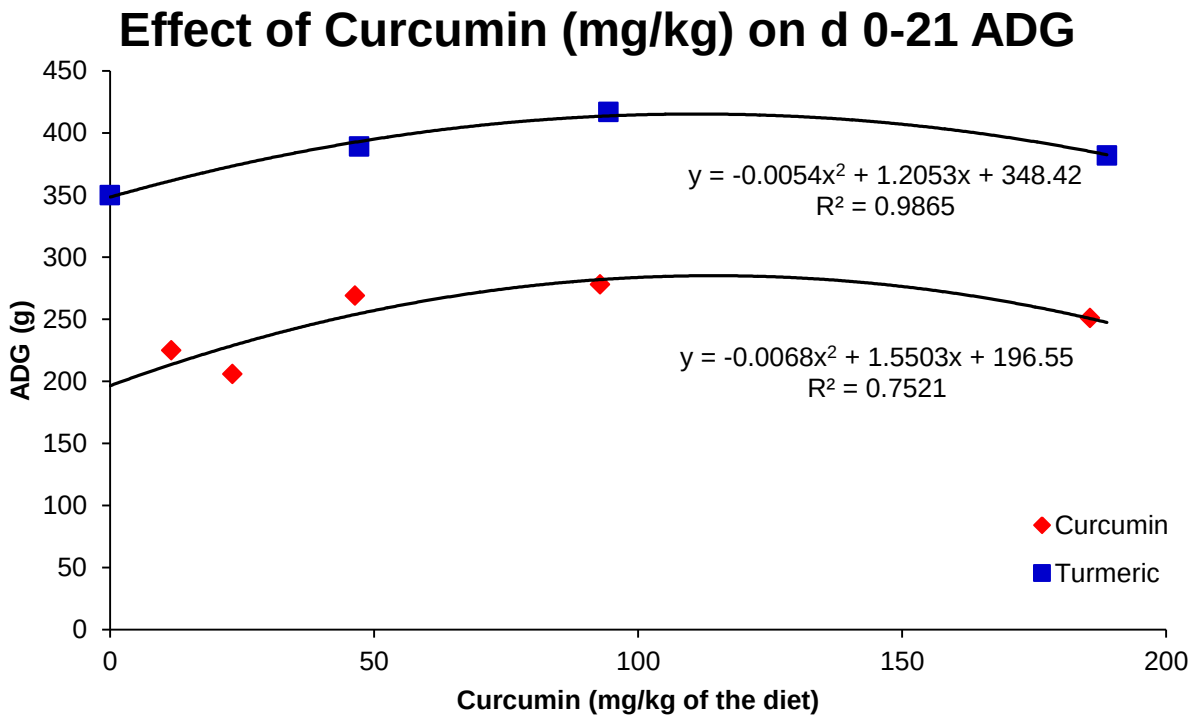

Figure VIII.8. Comparison of the curcumin vs. turmeric in regards to the relationship of curcumin in the diet (mg/kg) and d 0-21 ADG for Exp. I, II, and III.

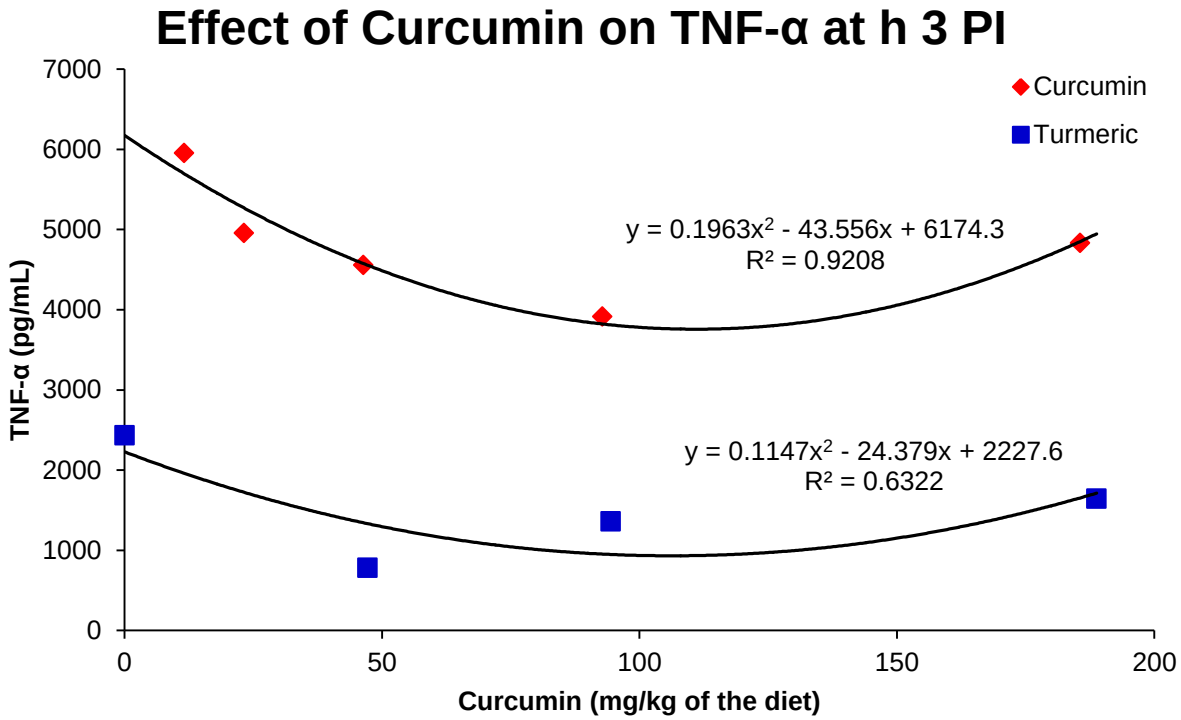

Figure VIII.9. Comparison of the curcumin vs. turmeric in regards to the relationship of curcumin in the diet (mg/kg) and TNF-α at h 3 PI for Exp. I, II, and III.

In conclusion, when feeding curcumin to pigs, the source of curcumin and supplier should be considered. The curcumin concentration should be analyzed and determined before feeding it to pigs. Curcumin improved growth performance and immunomodulated the immune response during a LPS challenge. Our studies show that in order to have maximum growth performance and an improved immune response, the level of curcumin is between 46 and 94 mg/kg. Therefore, curcumin has the potential to replace antibiotics in feed; however, more research is needed to determine the appropriate level of curcumin.

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APPENDIX 1

EXPERIMENT 1

Appendix 1 Table 1. Pig means for turmeric and curcumin intake

			Intake, mg/kg of BW/d	
Pig	**Rep**	**Trt**	**Turmeric**	**Curcumin**
13	1	CNT	0.0	0.00
11	2	CNT	0.0	0.00
7	3	CNT	0.0	0.00
16	4	CNT	0.0	0.00
20	5	CNT	0.0	0.00
21	6	CNT	0.0	0.00
28	7	CNT	0.0	0.00
29	8	CNT	0.0	0.00
1	1	2	81.0	1.91
15	2	2	101.4	2.39
4	3	2	80.4	1.90
5	4	2	92.9	2.19
17	5	2	84.7	2.00
24	6	2	79.1	1.87
25	7	2	98.1	2.31
32	8	2	99.9	2.36
2	1	4	173.8	4.10
3	2	4	.	.
8	3	4	201.8	4.76
6	4	4	.	.
19	5	4	186.2	4.40
22	6	4	185.6	4.38
27	7	4	195.8	4.62
30	8	4	171.2	4.04
12	1	8	271.3	6.40
10	2	8	353.9	8.35
14	3	8	361.5	8.53
9	4	8	.	.
18	5	8	349.2	8.24
23	6	8	361.2	8.52
26	7	8	409.7	9.67
31	8	8	350.7	8.28

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 2. Pig means for BW and ADG

			BW, kg				ADG, g			
Pig	**Rep**	**Trt**	**D0**	**D7**	**D14**	**D21**	**D0-7**	**D7-14**	**D14-21**	**D0-21**
13	1	CNT	8.6	10.1	11.2	15.9	207	181	590	346
11	2	CNT	7.3	9.2	11.2	16.8	272	333	703	454
7	3	CNT	7.9	8.3	10.2	13.3	65	317	385	259
16	4	CNT	6.4	7.7	9.1	12.8	181	227	465	302
20	5	CNT	8.3	9.4	11.4	15.9	168	285	635	363
21	6	CNT	7.4	8.6	11.5	15.6	168	415	583	389
28	7	CNT	6.8	8.3	10.7	15.5	207	350	387	415
29	8	CNT	7.1	8.1	9.3	12.9	143	181	505	276
1	1	2	8.3	8.7	10.4	14.4	65	287	499	294
15	2	2	7.3	8.5	10.0	14.9	181	544	567	432
4	3	2	8.8	9.7	12.2	16.6	130	423	544	371
5	4	2	6.8	8.1	9.3	13.8	194	197	556	333
17	5	2	8.8	10.4	13.2	17.7	233	402	635	423
24	6	2	7.4	8.9	11.9	15.6	207	428	531	389
25	7	2	6.8	8.2	11.0	15.7	194	402	674	423
32	8	2	6.5	8.3	11.2	16.0	246	415	687	449
2	1	4	7.7	8.5	10.0	14.9	117	241	612	341
3	2	4	.	.	.	.	.	.	.	.
8	3	4	6.8	8.2	11.0	15.4	194	469	556	410
6	4	4	.	.	.	.	.	.	.	.
19	5	4	8.7	10.0	13.8	18.8	164	531	713	479
22	6	4	7.6	9.4	12.1	17.8	259	376	816	484
27	7	4	7.1	8.5	12.0	16.8	207	492	687	462
30	8	4	6.4	8.3	10.6	12.5	272	324	415	337
12	1	8	8.5	9.8	10.2	14.4	181	60	533	281
10	2	8	7.4	8.4	11.2	16.5	143	469	658	432
14	3	8	7.3	8.3	11.9	16.6	130	605	590	441
9	4	8	.	.	.	.	.	.	.	.
18	5	8	8.1	9.3	11.8	15.8	168	363	570	367
23	6	8	7.2	8.3	10.9	16.3	168	363	777	436
26	7	8	6.8	8.0	11.1	16.6	168	441	790	466
31	8	8	6.4	7.8	10.1	13.5	194	324	492	337

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 3. Pig means for ADFI and G:F

			ADFI, g				G:F			
Pig	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D0-7**	**D7-14**	**D14-21**	**D0-21**
13	1	CNT	241	288	755	450	0.862	0.630	0.781	0.768
11	2	CNT	263	423	855	534	1.036	0.787	0.822	0.849
7	3	CNT	178	310	664	401	0.364	1.023	0.581	0.647
16	4	CNT	221	374	755	468	0.821	0.607	0.616	0.646
20	5	CNT	315	418	737	490	0.535	0.682	0.862	0.741
21	6	CNT	207	486	819	504	0.815	0.852	0.712	0.771
28	7	CNT	261	367	763	463	0.795	0.954	0.901	0.895
29	8	CNT	226	276	564	355	0.630	0.658	0.895	0.778
1	1	2	206	373	651	423	0.315	0.770	0.766	0.694
15	2	2	271	522	831	556	0.670	1.042	0.682	0.776
4	3	2	212	382	777	476	0.611	1.109	0.700	0.781
5	4	2	248	301	718	442	0.785	0.652	0.774	0.752
17	5	2	332	513	748	531	0.703	0.783	0.848	0.797
24	6	2	275	505	520	433	0.754	0.847	1.021	0.897
25	7	2	232	482	817	510	0.840	0.833	0.824	0.829
32	8	2	288	460	822	523	0.855	0.901	0.835	0.858
2	1	4	240	335	711	446	0.486	0.723	0.861	0.764
3	2	4	.	.	.	.	.	.	.	.
8	3	4	237	461	813	522	0.822	1.004	0.684	0.786
6	4	4	.	.	.	.	.	.	.	.
19	5	4	348	549	896	598	0.558	0.968	0.796	0.802
22	6	4	306	473	853	544	0.846	0.795	0.957	0.889
27	7	4	276	489	863	543	0.751	1.006	0.796	0.852
30	8	4	290	367	592	416	0.937	0.883	0.701	0.809
12	1	8	283	229	536	364	0.642	0.264	0.994	0.772
10	2	8	224	407	765	483	0.635	1.151	0.860	0.895
14	3	8	225	522	719	498	0.577	1.159	0.819	0.885
9	4	8	.	.	.	.	.	.	.	.
18	5	8	306	417	747	490	0.551	0.869	0.764	0.749
23	6	8	206	417	824	482	0.818	0.870	0.944	0.905
26	7	8	265	507	858	544	0.635	0.869	0.921	0.858
31	8	8	233	376	634	414	0.833	0.862	0.776	0.813

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 4. Pig means for BW loss from h 0 and feed intake for LPS challenge

			BW loss from H0, %				Feed Intake, g
Pig	Rep	Trt	H3	H6	H12	H24	H12-24
13	1	CNT	98.3	97.1	96.6	105.1	604
11	2	CNT	97.8	97.3	95.1	102.7	622
7	3	CNT	96.6	98.0	95.9	104.8	499
16	4	CNT	98.6	98.6	98.6	99.3	225
20	5	CNT	96.3	96.3	92.7	94.5	702
21	6	CNT	98.7	97.4	95.5	104.5	467
28	7	CNT	100.0	100.8	99.2	101.7	148
29	8	CNT	96.5	94.1	95.3	101.8	335
1	1	2	96.6	96.0	93.7	101.7	693
15	2	2	98.6	95.1	93.7	97.2	710
4	3	2	97.1	95.9	94.8	101.7	769
5	4	2	95.3	94.7	93.0	91.8	430
17	5	2	95.7	94.2	92.3	90.3	141
24	6	2	96.4	95.4	93.9	96.9	82
25	7	2	96.2	94.1	92.4	90.3	736
32	8	2	96.6	94.0	92.6	88.6	668
2	1	4	97.5	97.5	95.6	103.8	253
3	2	4	.	.	.	.	.
8	3	4	97.8	96.7	95.0	104.4	651
6	4	4	.	.	.	.	.
19	5	4	101.6	100.8	99.2	103.3	59
22	6	4	97.3	94.5	94.5	102.2	374
27	7	4	98.1	96.9	92.5	91.2	135
30	8	4	97.8	97.3	95.1	105.5	.
12	1	8	97.7	96.5	94.8	102.3	203
10	2	8	98.8	98.8	97.1	95.9	775
14	3	8	97.7	94.9	92.6	102.8	844
9	4	8	.	.	.	.	.
18	5	8	97.7	96.6	96.0	100.6	458
23	6	8	98.3	98.9	93.9	95.6	283
26	7	8	97.8	96.2	93.4	103.3	816
31	8	8	98.7	98.0	95.3	98.0	190

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 5. Pig means for rectal temperature and changes in rectal temperature for LPS challenge

			Rectal Temperature, °C					Changes in Rectal Temperature			
Pig	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H12**	**H24**	**H3**	**H6**	**H12**	**H24**
13	1	CNT	39.1	41.2	40.8	40.7	39.3	2.11	1.67	1.55	0.17
11	2	CNT	39.3	40.1	40.5	40.2	39.6	0.78	1.17	0.83	0.28
7	3	CNT	40.3	41.3	40.3	40.0	39.2	1.05	0.06	-0.28	-1.05
16	4	CNT	40.1	41.4	40.2	40.5	40.2	1.33	0.11	0.39	0.11
20	5	CNT	39.4	40.9	40.1	39.8	39.3	1.50	0.72	0.39	-0.11
21	6	CNT	39.9	40.8	39.5	40.5	39.2	0.89	-0.44	0.61	-0.67
28	7	CNT	39.8	41.3	41.0	40.9	39.2	1.50	1.17	1.05	-0.61
29	8	CNT	39.3	40.8	40.3	40.5	39.2	1.50	1.05	1.17	-0.06
1	1	2	39.6	40.8	39.8	39.5	39.5	1.17	0.17	-0.11	-0.11
15	2	2	39.2	40.6	40.8	40.2	39.4	1.39	1.67	1.05	0.22
4	3	2	40.1	40.5	40.6	40.2	40.0	0.33	0.50	0.11	-0.17
5	4	2	39.3	40.1	40.1	40.2	39.7	0.78	0.83	0.89	0.44
17	5	2	39.8	40.8	41.5	41.2	39.1	0.94	1.67	1.33	-0.78
24	6	2	40.1	40.4	40.4	41.0	40.0	0.28	0.28	0.89	-0.11
25	7	2	39.8	40.3	40.4	40.2	39.5	0.44	0.56	0.33	-0.39
32	8	2	39.6	41.2	41.2	40.5	39.5	1.61	1.55	0.89	-0.17
2	1	4	39.8	41.2	41.0	40.5	39.7	1.33	1.17	0.67	-0.17
3	2	4	.	.	.	.	.	.	.	.	.
8	3	4	39.5	41.2	41.1	40.1	39.6	1.78	1.61	0.67	0.11
6	4	4	.	.	.	.	.	.	.	.	.
19	5	4	40.2	41.3	41.1	40.5	39.6	1.17	0.89	0.33	-0.56
22	6	4	40.0	40.7	40.4	40.2	39.5	0.67	0.39	0.17	-0.56
27	7	4	40.2	40.3	40.2	41.2	39.7	0.11	0.00	1.00	-0.50
30	8	4	39.3	40.6	41.1	41.6	38.7	1.22	1.72	2.22	-0.61
12	1	8	39.6	40.8	40.5	41.0	39.7	1.17	0.89	1.39	0.11
10	2	8	39.7	40.6	40.1	39.7	39.3	0.94	0.44	0.00	-0.39
14	3	8	39.3	41.0	41.2	40.1	39.7	1.72	1.94	0.78	0.39
9	4	8	.	.	.	.	.	.	.	.	.
18	5	8	40.0	41.4	41.1	40.0	39.2	1.39	1.05	-0.06	-0.78
23	6	8	39.5	40.9	40.9	40.7	39.2	1.39	1.39	1.17	-0.33
26	7	8	39.8	40.2	40.8	41.2	40.0	0.33	0.94	1.33	0.17
31	8	8	39.1	41.1	40.7	40.1	39.4	1.94	1.55	0.94	0.28

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 6. Pig means for TNF-α and changes in TNF-α for LPS challenge

			TNF-α, pg/mL				Changes in TNF-α		
Pig	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
13	1	CNT	73.2	1454	380	360	1380	307	286
11	2	CNT	63.1	963	342	78.6	900	279	15.5
7	3	CNT	35.1	3192	717	57.8	3157	682	22.7
16	4	CNT	101	1108	293	89.3	1008	192	-11.5
20	5	CNT	32.4	2510	742	52.8	2478	710	20.5
21	6	CNT	38.9	1286	331	49.3	1247	292	10.4
28	7	CNT	61.7	6686	1558	66.7	6624	1496	5.0
29	8	CNT	22.8	2270	604	45.8	2247	581	23.1
1	1	2	64.6	1296	515	178	1232	450	114
15	2	2	47.4	274	191	29.6	226	144	-17.7
4	3	2	50.1	478	165	33.9	428	115	-16.2
5	4	2	54.9	1672	530	60.8	1617	475	5.9
17	5	2	23.7	1019	417	60.6	995	394	36.8
24	6	2	66.4	175	229	47.9	109	163	-18.6
25	7	2	46.3	499	186	37.2	453	140	-9.1
32	8	2	17.0	843	285	18.2	826	268	1.2
2	1	4	38.5	1401	450	11.6	1362	411	-26.9
3	2	4	.	.	.	.	.	.	.
8	3	4	55.4	3358	632	51.7	3303	577	-3.6
6	4	4	.	.	.	.	.	.	.
19	5	4	24.6	2319	949	64.6	2294	925	40.0
22	6	4	38.9	1343	552	39.6	1304	513	0.7
27	7	4	22.2	58	82	29.9	36.0	60.0	7.7
30	8	4	40.5	685	520	62.0	645	480	21.5
12	1	8	.	.	.	.	.	.	.
10	2	8	9.3	1124	413	24.7	1114	404	15.4
14	3	8	26.9	701	356	40.1	674	329	13.2
9	4	8	36.7	4013	1587	53.1	3976	1550	16.4
18	5	8	29.6	1633	454	53.7	1603	424	24.1
23	6	8	33.2	1089	393	35.7	1056	360	2.5
26	7	8	42.2	213	252	32.2	171	210	-10.0
31	8	8	52.8	2878	637	63.9	2825	584	11.2

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 7. Pig means for CRP and changes in CRP for LPS challenge

			CRP, mg/mL				Changes in CRP		
Pig	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
13	1	CNT	2.05	1.70	.	.	-0.35	.	.
11	2	CNT	0.60	0.70	1.15	3.75	0.10	0.55	3.15
7	3	CNT	1.85	2.45	2.20	3.50	0.60	0.35	1.65
16	4	CNT	6.15	5.95	4.85	5.35	-0.20	-1.30	-0.80
20	5	CNT	0.30	0.40	0.70	2.30	0.10	0.40	2.00
21	6	CNT	0.90	1.00	1.70	4.55	0.10	0.80	3.65
28	7	CNT	0.45	0.75	1.30	3.30	0.30	0.85	2.85
29	8	CNT	0.80	0.80	1.10	5.75	0.00	0.30	4.95
1	1	2	1.30	1.20	1.70	1.95	-0.10	0.40	0.65
15	2	2	1.50	1.40	1.75	5.65	-0.10	0.25	4.15
4	3	2	3.40	2.75	3.20	6.50	-0.65	-0.20	3.10
5	4	2	2.60	2.40	2.40	5.05	-0.20	-0.20	2.45
17	5	2	2.85	2.15	2.85	4.40	-0.70	0.00	1.55
24	6	2	1.50	1.20	1.60	5.05	-0.30	0.10	3.55
25	7	2	1.75	1.75	2.10	5.50	0.00	0.35	3.75
32	8	2	0.60	0.80	0.90	1.85	0.20	0.30	1.25
2	1	4	1.85	1.15	2.20	5.15	-0.70	0.35	3.30
3	2	4	.	.	.	.	.	.	.
8	3	4	1.40	1.25	1.70	3.20	-0.15	0.30	1.80
6	4	4	.	.	.	.	.	.	.
19	5	4	0.70	0.75	1.40	3.95	0.05	0.70	3.25
22	6	4	0.60	1.95	1.15	2.60	1.35	0.55	2.00
27	7	4	0.75	0.85	1.25	6.25	0.10	0.50	5.50
30	8	4	0.10	0.20	0.60	5.05	0.10	0.50	4.95
12	1	8	.	.	.	.	.	.	.
10	2	8	1.25	0.75	1.45	4.90	-0.50	0.20	3.65
14	3	8	1.40	1.25	1.80	2.50	-0.15	0.40	1.10
9	4	8	1.85	1.50	1.80	4.50	-0.35	-0.05	2.65
18	5	8	1.00	0.95	1.40	1.70	-0.05	0.40	0.70
23	6	8	1.60	1.80	2.30	5.80	0.20	0.70	4.20
26	7	8	1.10	1.10	1.90	4.75	0.00	0.80	3.65
31	8	8	1.30	1.30	1.60	1.45	0.00	0.30	0.15

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 8. Pig means for BUN and changes in BUN for LPS challenge

			BUN, mg/dL				Changes in BUN		
Pig	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
13	1	CNT	10.0	9.5	.	11.5	-0.5	.	1.5
11	2	CNT	14.5	13.5	16.0	15.5	-1.0	1.5	1.0
7	3	CNT	10.0	13.0	12.0	10.0	3.0	2.0	0.0
16	4	CNT	17.0	16.0	16.0	15.5	-1.0	-1.0	-1.5
20	5	CNT	9.0	9.0	14.5	11.0	0.0	5.5	2.0
21	6	CNT	9.0	7.5	7.0	12.0	-1.5	-2.0	3.0
28	7	CNT	10.5	7.0	9.0	13.0	-3.5	-1.5	2.5
29	8	CNT	6.0	10.0	9.0	11.5	4.0	3.0	5.5
1	1	2	13.0	12.5	13.0	17.5	-0.5	0.0	4.5
15	2	2	11.0	11.0	16.5	17.0	0.0	5.5	6.0
4	3	2	13.0	13.5	15.0	14.0	0.5	2.0	1.0
5	4	2	6.5	9.0	11.5	12.0	2.5	5.0	5.5
17	5	2	12.0	10.5	9.0	15.0	-1.5	-3.0	3.0
24	6	2	10.5	10.0	12.5	11.0	-0.5	2.0	0.5
25	7	2	10.0	9.0	12.0	12.0	-1.0	2.0	2.0
32	8	2	12.5	5.5	16.5	14.0	-7.0	4.0	1.5
2	1	4	9.5	12.0	12.5	9.0	2.5	3.0	-0.5
3	2	4	.	.	.	.	.	.	.
8	3	4	10.0	7.5	10.0	16.0	-2.5	0.0	6.0
6	4	4	.	.	.	.	.	.	.
19	5	4	12.0	12.0	9.0	15.0	0.0	-3.0	3.0
22	6	4	11.0	11.0	14.0	13.0	0.0	3.0	2.0
27	7	4	13.0	8.0	12.0	15.0	-5.0	-1.0	2.0
30	8	4	13.5	5.0	11.0	18.0	-8.5	-2.5	4.5
12	1	8	13.0	14.0	12.5	18.0	1.0	-0.5	5.0
10	2	8	9.0	8.0	11.0	15.0	-1.0	2.0	6.0
14	3	8	8.0	6.5	9.5	16.0	-1.5	1.5	8.0
9	4	8	.	.	.	.	.	.	.
18	5	8	7.0	7.5	14.0	12.5	0.5	7.0	5.5
23	6	8	11.0	11.5	15.5	16.0	0.5	4.5	5.0
26	7	8	7.5	7.0	7.0	12.0	-0.5	-0.5	4.5
31	8	8	12.0	15.5	16.0	14.0	3.5	4.0	2.0

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 9. Pig means for glucose and changes in glucose for LPS challenge

			Glucose, mg/dL				Changes in Glucose		
Pig	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
13	1	CNT	104	84	.	111	-20.0	.	6.5
11	2	CNT	121	90	84	114	-30.5	-37.0	-6.5
7	3	CNT	114	42	83	113	-72.0	-30.5	-1.0
16	4	CNT	104	77	64	76	-26.5	-40.0	-28.0
20	5	CNT	111	91	133	101	-20.0	22.5	-9.5
21	6	CNT	117	142	175	101	24.5	58.0	-16.0
28	7	CNT	123	153	111	140	29.5	-12.5	17.0
29	8	CNT	122	86	117	94	-36.0	-4.5	-28.0
1	1	2	123	113	96	117	-10.0	-27.0	-5.5
15	2	2	121	68	81	111	-53.0	-40.5	-10.5
4	3	2	138	129	100	120	-9.0	-38.0	-18.0
5	4	2	146	122	98	125	-24.0	-48.5	-21.5
17	5	2	127	120	85	90	-7.0	-42.0	-36.5
24	6	2	140	120	104	87	-20.0	-36.0	-53.0
25	7	2	145	124	127	128	-21.0	-18.5	-17.0
32	8	2	134	142	79	112	8.0	-54.5	-21.5
2	1	4	137	129	45	161	-7.5	-92.0	24.5
3	2	4	.	.	.	.	.	.	.
8	3	4	132	71	81	113	-61.5	-51.5	-19.5
6	4	4	.	.	.	.	.	.	.
19	5	4	143	155	155	88	12.0	12.5	-54.5
22	6	4	137	127	109	103	-9.5	-27.5	-33.5
27	7	4	128	147	143	150	19.0	14.5	21.5
30	8	4	119	147	137	76	27.5	17.5	-43.0
12	1	8	129	100	85	94	-29.5	-44.0	-35.0
10	2	8	126	104	78	136	-22.0	-47.5	10.5
14	3	8	120	95	82	118	-25.5	-38.5	-2.5
9	4	8	.	.	.	.	.	.	.
18	5	8	128	131	82	105	3.0	-45.5	-22.5
23	6	8	127	129	90	91	2.0	-37.0	-36.5
26	7	8	137	128	128	132	-9.0	-9.0	-4.5
31	8	8	116	85	77	108	-31.0	-39.0	-8.0

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 10. Pig means for total protein and changes in total protein for LPS challenge

			Total Protein, g/dL				Changes in Total Protein		
Pig	Rep	Trt	H0	H3	H6	H24	H3	H6	H24
13	1	CNT	5.3	4.7	.	4.9	-0.65	.	-0.45
11	2	CNT	5.1	5.2	4.9	5.1	0.10	-0.20	0.00
7	3	CNT	5.6	5.6	5.2	5.5	0.00	-0.35	-0.10
16	4	CNT	5.1	5.0	4.7	4.9	-0.10	-0.40	-0.20
20	5	CNT	5.3	5.0	5.8	4.7	-0.25	0.50	-0.60
21	6	CNT	6.0	4.8	5.5	5.3	-1.20	-0.50	-0.70
28	7	CNT	5.5	4.4	5.3	4.8	-1.05	-0.20	-0.70
29	8	CNT	5.2	6.1	6.0	4.8	0.90	0.85	-0.35
1	1	2	5.2	4.4	4.3	5.1	-0.80	-0.95	-0.10
15	2	2	5.5	5.8	5.4	5.3	0.30	-0.10	-0.20
4	3	2	6.1	5.8	5.5	5.8	-0.25	-0.60	-0.30
5	4	2	5.6	5.4	5.2	5.2	-0.20	-0.40	-0.45
17	5	2	5.6	4.5	5.9	3.0	-1.10	0.25	-2.65
24	6	2	5.9	5.3	5.9	5.4	-0.65	0.00	-0.50
25	7	2	6.0	6.2	5.6	5.7	0.25	-0.35	-0.25
32	8	2	5.8	5.3	4.7	5.0	-0.55	-1.10	-0.80
2	1	4	5.4	4.9	4.9	5.0	-0.45	-0.50	-0.40
3	2	4	.	.	.	.	.	.	.
8	3	4	6.0	5.9	5.5	5.5	-0.10	-0.45	-0.50
6	4	4	.	.	.	.	.	.	.
19	5	4	5.3	4.5	6.0	5.0	-0.80	0.65	-0.30
22	6	4	5.5	4.5	5.3	4.9	-1.00	-0.20	-0.55
27	7	4	6.1	5.6	5.3	5.3	-0.55	-0.80	-0.85
30	8	4	5.5	5.2	5.5	4.8	-0.25	0.00	-0.70
12	1	8	4.7	4.6	4.4	4.8	-0.05	-0.30	0.15
10	2	8	5.6	5.1	5.1	5.1	-0.45	-0.45	-0.45
14	3	8	5.4	5.7	4.7	5.0	0.30	-0.65	-0.40
9	4	8	.	.	.	.	.	.	.
18	5	8	5.4	4.8	5.0	4.7	-0.65	-0.45	-0.75
23	6	8	5.5	5.0	5.8	5.5	-0.55	0.30	0.00
26	7	8	5.6	5.2	5.4	4.9	-0.35	-0.15	-0.70
31	8	8	5.8	6.2	4.8	5.2	0.40	-1.05	-0.65

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 11. Pig means for triglycerides and changes in triglycerides for LPS challenge

			Triglycerides, mg/mL				Changes in Triglycerides		
Pig	Rep	Trt	H0	H3	H6	H24	H3	H6	H24
13	1	CNT	21	24	.	50	3.0	.	28.5
11	2	CNT	21	37	46	50	15.5	24.5	29.0
7	3	CNT	37	66	47	49	29.0	10.5	12.0
16	4	CNT	50	53	34	43	3.5	-15.5	-6.5
20	5	CNT	26	27	82	67	1.0	56.5	41.0
21	6	CNT	38	43	14	43	5.0	-23.5	5.0
28	7	CNT	14	24	26	37	10.5	12.0	23.0
29	8	CNT	27	103	38	44	76.5	11.0	17.0
1	1	2	38	32	26	36	-5.5	-11.5	-1.5
15	2	2	33	60	66	38	27.0	33.0	4.5
4	3	2	34	40	32	50	6.0	-2.5	16.0
5	4	2	54	81	62	44	26.5	7.5	-10.5
17	5	2	91	85	67	25	-5.5	-23.5	-65.5
24	6	2	34	23	103	40	-11.5	68.5	5.5
25	7	2	32	26	91	27	-5.5	59.0	-5.0
32	8	2	15	13	19	16	-2.0	3.5	1.0
2	1	4	71	61	29	81	-10.0	-42.0	10.0
3	2	4	.	.	.	.	.	.	.
8	3	4	45	40	36	36	-5.0	-9.0	-9.5
6	4	4	.	.	.	.	.	.	.
19	5	4	25	39	30	40	14.5	5.0	15.5
22	6	4	51	41	76	17	-10.0	25.0	-34.0
27	7	4	40	36	25	38	-4.0	-15.5	-2.5
30	8	4	40	46	51	66	6.0	11.5	26.0
12	1	8	40	43	27	48	3.0	-13.0	7.5
10	2	8	22	29	48	60	7.5	26.0	38.0
14	3	8	26	30	51	37	4.5	25.5	11.0
9	4	8	.	.	.	.	.	.	.
18	5	8	41	41	79	40	0.5	38.0	-0.5
23	6	8	25	15	87	23	-10.0	62.0	-2.0
26	7	8	41	43	41	37	2.0	0.0	-3.5
31	8	8	26	118	33	35	92.5	7.5	9.0

CNT = control diet containing no antibiotics or zinc
2 = 2 g/kg of turmeric powder
4 = 4 g/kg of turmeric powder
8 = 8 g/kg of turmeric powder

Appendix 1 Table 12. Analysis of variance for turmeric and curcumin intake

		Mean square	
Source	**df**	**Turmeric**	**Curcumin**
Total	28		
Rep	7	0.00060280	0.3357342
Trt	3	0.16654305	92.7578171
Linear	1	0.48938679	272.5688686
Quadratic	1	0.0035114	0.1955720
Cubic	1	0.0015598	0.0868761
CNT vs. TUM	1	0.25059722	139.5726262
Error	18	0.00039676	0.2209767
CV, %		13.47	13.47

Appendix 1 Table 13. Analysis of variance for BW

		Mean square			
Source	**df**	**D0**	**D7**	**D14**	**D21**
Total	28				
Rep	7	1.95045330	1.40090763	2.80942088	4.91902456
Trt	3	0.11378286	0.26397226	1.85498257	2.90797610
Linear	1	0.21905853	0.37697620	0.03418646	0.94598160
Quadratic	1	0.07773512	0.43715342	5.40727610	7.56166274
Cubic	1	0.03606794	0.00014866	0.00421247	0.13802908
CNT vs. TUM	1	0.00447602	0.00089946	3.04722797	6.21171181
Error	18	0.11952444	0.25792881	0.40148359	1.09713518
CV, %		4.63	5.81	5.70	6.73

Appendix 1 Table 14. Analysis of variance for ADG

		Mean square			
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**
Total	28				
Rep	7	0.00429940	0.02930399	0.02218969	0.00866690
Trt	3	0.00125939	0.02819490	0.00529278	0.00642222
Linear	1	0.00043470	0.01579964	0.01114967	0.00470630
Quadratic	1	0.00298374	0.06533340	0.00328893	0.01384587
Cubic	1	0.00083363	0.00008365	0.00157986	0.00071477
CNT vs. TUM	1	0.00019160	0.07035769	0.01017605	0.01485187
Error	18	0.00220364	0.00708036	0.00825824	0.00223422
CV, %		25.88	23.37	15.10	12.25

Appendix 1 Table 15. Analysis of variance for ADFI

		Mean square			
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**
Total	28				
Rep	7	0.00419487	0.01403860	0.01575649	0.00665826
Trt	3	0.00174513	0.01095624	0.00640021	0.00449543
Linear	1	0.00008635	0.00198733	0.00008116	0.00010932
Quadratic	1	0.00504662	0.02728188	0.01196031	0.01307765
Cubic	1	0.00030152	0.00084987	0.01007559	0.00095258
CNT vs. TUM	1	0.00255752	0.02489166	0.00129621	0.00596561
Error	18	0.00076629	0.00391303	0.00895199	0.00198383
CV, %		10.83	15.07	12.70	9.29

Appendix 1 Table 16. Analysis of variance for G:F

		Mean square			
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**
Total	28				
Rep	7	0.05392822	0.07866325	0.07866325	0.00967816
Trt	3	0.00361053	0.04172289	0.04172289	0.00675694
Linear	1	0.00553620	0.01684647	0.01684647	0.01648681
Quadratic	1	0.00013219	0.10346298	0.10346298	0.00309007
Cubic	1	0.00468959	0.00767955	0.00767955	0.00000491
CNT vs. TUM	1	0.00706881	0.08266986	0.08266986	0.01694621
Error	18	0.02131247	0.01731522	0.01731522	0.00282312
CV, %		20.67	15.54	15.54	6.62

Appendix 1 Table 17. Analysis of variance for % BW loss from h 0 for LPS challenge

		Mean square			
Source	**df**	**H3**	**H6**	**H12**	**H24**
Total	28				
Rep	7	0.63253711	0.70216828	0.70124445	25.3537997
Trt	3	4.71163221	11.02758810	11.13914361	82.2587359
Linear	1	2.00140605	1.05484568	0.78957936	0.1961495
Quadratic	1	0.08657895	3.98107544	5.03809168	5.9769490
Cubic	1	11.78761048	24.80595084	23.43080316	241.1337639
CNT vs. TUM	1	0.16000149	5.78764531	15.05010818	45.9695945
Error	18	1.62393047	3.30225772	3.7761393	17.0969551
CV, %		1.30	1.88	2.05	4.16

Appendix 1 Table 18. Analysis of variance for feed intake for LPS challenge

		Mean square
Source	**df**	**H12-24**
Total	28	
Rep	7	0.07828575
Trt	3	0.05632195
Linear	1	0.00516946
Quadratic	1	0.04326812
Cubic	1	0.12888850
CNT vs. TUM	1	0.00092303
Error	18	0.05658887
CV, %		50.95

Appendix 1 Table 19. Analysis of variance for rectal temperature for LPS challenge

		Mean square				
Source	**df**	**H0**	**H3**	**H6**	**H12**	**H24**
Total	28					
Rep	7	0.20939436	0.19868270	0.17025236	0.24428447	0.13439458
Trt	3	0.07251085	0.24871164	0.30875502	0.14437913	0.03676005
Linear	1	0.03296106	0.00001033	0.53244535	0.00003315	0.03389126
Quadratic	1	0.18726444	0.21303187	0.34265534	0.13509654	0.00444538
Cubic	1	0.03929584	0.41294736	0.00630850	0.09100557	0.08103844
CNT vs. TUM	1	0.01181464	0.30205226	0.80603359	0.02267234	0.07551306
Error	18	0.10238054	0.14638469	0.23018740	0.26497720	0.9785179
CV, %		0.81	0.94	1.18	1.27	0.79

Appendix 1 Table 20. Fixed effects for changes in rectal temperature for LPS challenge

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	118	0.53	0.6605
Hr	4	118	61.56	<0.0001
Trt x Hr	12	118	1.17	0.3117

Appendix 1 Table 21. Analysis of variance for TNF-α for LPS challenge

		Mean square			
Source	**Df**	**H0**	**H3**	**H6**	**H24**
Total	28				
Rep	7	444.720880	407317.83	49596.9932	3541.78722
Trt	3	637.946542	3656869.69	148180.8844	5389.72773
Linear	1	1153.234409	402307.168	6393.4050	10242.35181
Quadratic	1	216.675169	4389224.831	91463.7499	2366.94022
Cubic	1	30.313958	4504338.280	281857.8655	919.33660
CNT vs. TUM	1	1045.581568	7051785.894	115880.3608	13430.92987
Error	18	313.51461	2305043.89	149414.371	4166.7178
CV, %		41.10	94.61	75.93	102.34

Appendix 1 Table 22. Fixed effects for changes in TNF-α for LPS challenge

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	93	2.17	0.0964
Hr	3	93	38.60	<0.0001
Trt x Hr	9	93	2.10	0.0371

Appendix 1 Table 23. Analysis of variance for CRP for LPS challenge

		Mean square			
Source	**df**	**H0**	**H3**	**H6**	**H24**
Total	28				
Rep	7	2.44307988	1.82627427	1.08600724	1.97928378
Trt	3	1.32845238	0.83584257	0.54296627	0.99015377
Linear	1	0.41746744	0.61005004	0.07281349	1.61901854
Quadratic	1	1.13554830	0.92358818	0.52971728	1.41387896
Cubic	1	2.17085491	0.65065421	0.96414132	0.01701907
CNT vs. TUM	1	0.46383447	0.86340155	0.12120312	0.01209395
Error	18	0.97100465	0.90918203	0.59189268	2.51864488
CV, %		65.69	65.53	43.04	38.23

Appendix 1 Table 24. Fixed effects for changes in CRP for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	91	1.06	0.3702
Hr	3	91	79.11	<0.0001
Trt x Hr	9	91	0.70	0.7100

Appendix 1 Table 25. Analysis of variance for BUN for LPS challenge

		Mean square			
Source	df	H0	H3	H6	H24
Total	28				
Rep	7	1.26024027	6.48619554	5.40584913	3.51119916
Trt	3	4.23907020	2.38110632	4.29662698	7.48920703
Linear	1	5.13129546	1.17324531	0.12964788	18.52191008
Quadratic	1	8.20300518	3.59409044	0.10376369	5.08603227
Cubic	1	0.99486201	0.34122455	9.24770442	0.35543403
CNT vs. TUM	1	0.00648721	3.59058726	0.91796286	23.23118531
Error	18	8.5141228	10.4064101	10.0888380	6.5501256
CV, %		27.21	32.04	25.89	18.46

Appendix 1 Table 26. Fixed effects for changes in BUN for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	92	2.87	0.0406
Hr	3	92	17.21	<0.0001
Trt x Hr	9	92	1.17	0.3267

Appendix 1 Table 27. Analysis of variance for glucose for LPS challenge

		Mean square			
Source	**df**	**H0**	**H3**	**H6**	**H24**
Total	28				
Rep	7	51.294516	1362.015274	1379.615193	920.608932
Trt	3	622.013376	1401.513376	803.908234	98.839901
Linear	1	199.758731	75.225121	1407.850821	85.8899454
Quadratic	1	1090.809986	2322.560520	144.575037	369.5296595
Cubic	1	247.611422	0.008088	950.186363	41.8514103
CNT vs. TUM	1	1433.289134	1535.121208	725.963095	304.6283926
Error	18	73.371742	525.20256	659.65941	286.92589
CV, %		6.79	20.50	25.50	15.31

Appendix 1 Table 28. Fixed effects for changes in glucose for LPS challenge

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	92	2.09	0.1073
Hr	3	92	7.33	0.0002
Trt x Hr	9	92	1.16	0.3281

Appendix 1 Table 29. Analysis of variance for total protein for LPS challenge

		Mean square			
Source	**df**	**H0**	**H3**	**H6**	**H24**
Total	28				
Rep	7	0.16243070	0.63623125	0.43206241	0.41331138
Trt	3	0.19244612	0.10094520	0.19129960	0.00857759
Linear	1	0.01826647	0.01697270	0.22087673	0.00319184
Quadratic	1	0.37743496	0.02534068	0.26813894	0.06810690
Cubic	1	0.07254585	0.11305020	0.02045283	0.01484767
CNT vs. TUM	1	0.17629002	0.09861143	0.00035860	0.03142133
Error	18	0.07938459	0.20092495	0.14818088	0.21975391
CV, %		5.11	8.66	7.33	9.35

Appendix 1 Table 30. Fixed effects for changes in total protein for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	92	1.12	0.3457
Hr	3	92	6.69	0.0004
Trt x Hr	9	92	0.50	0.8734

Appendix 1 Table 31. Analysis of variance for triglycerides for LPS challenge

		Mean square			
Source	df	H0	H3	H6	H24
Total	28				
Rep	7	216.586722	701.171271	841.165596	227.755746
Trt	3	428.217655	11.975575	518.602679	285.333675
Linear	1	12.4631146	16.47072670	389.248231	53.2319420
Quadratic	1	887.7378900	55.92701376	89.900771	1.3349237
Cubic	1	19.6791226	18.76954810	1825.799749	873.7357380
CNT vs. TUM	1	597.2128762	0.72526860	1086.616406	252.6326980
Error	18	256.333256	695.80145	489.68838	180.824816
CV, %		44.22	58.17	45.58	32.27

Appendix 1 Table 32. Fixed effects for changes in triglycerides for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	92	2.21	0.0927
Hr	3	92	1.57	0.2015
Trt x Hr	9	92	1.01	0.4375

APPENDIX 2

EXPERIMENT 2

Appendix 2 Table 1. Pen means for BW

			BW, kg				
Pen	**Rep**	**Trt**	**D0**	**D7**	**D14**	**D21**	**D42**
9	1	CNT	7.6	9.1	11.4	17.5	27.3
4	2	CNT	6.2	7.4	9.6	15.3	25.5
12	3	CNT	4.4	5.6	7.4	12.0	21.1
1	4	CNT	6.8	9.1	10.2	13.6	27.6
3	5	CNT	5.8	7.1	8.0	10.7	23.3
12	6	CNT	4.6	6.2	7.1	10.1	20.6
10	7	CNT	5.8	6.2	7.8	10.9	21.9
6	8	CNT	5.0	5.7	7.3	10.1	20.4
2	1	AB	7.4	8.9	11.5	17.2	26.9
11	2	AB	6.3	7.6	10.0	16.1	25.6
13	3	AB	4.5	5.9	8.2	13.8	22.4
9	4	AB	6.8	8.8	10.2	13.7	27.6
4	5	AB	5.7	7.9	9.3	13.2	25.6
13	6	AB	4.6	6.5	7.7	11.1	22.9
11	7	AB	5.8	6.2	7.9	10.7	23.5
14	8	AB	5.0	5.7	7.5	9.9	21.6
8	1	TUM	7.4	8.9	11.4	16.9	26.1
3	2	TUM	6.3	7.9	10.0	15.4	24.3
6	3	TUM	4.5	6.0	7.7	12.0	20.4
8	4	TUM	6.8	8.6	10.0	13.7	25.6
10	5	TUM	5.8	7.2	8.3	11.8	24.7
6	6	TUM	4.5	6.3	7.2	10.1	21.7
3	7	TUM	5.8	6.2	8.0	10.5	20.9
12	8	TUM	5.0	5.3	6.7	9.3	20.6
1	1	CUR	7.5	8.9	11.3	17.0	27.2
10	2	CUR	6.2	7.8	9.7	15.0	24.6
5	3	CUR	4.6	6.2	8.2	12.9	22.1
2	4	CUR	6.8	8.6	9.6	13.9	27.8
11	5	CUR	5.7	7.6	8.6	12.8	25.6
5	6	CUR	4.6	6.7	7.6	11.0	22.8
5	7	CUR	5.8	6.4	8.7	11.9	23.3
13	8	CUR	5.0	5.3	7.1	10.0	20.5

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 2. Pen means for ADG

			ADG, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
9	1	CNT	244	388	509	413	650	504
4	2	CNT	215	366	478	384	678	497
12	3	CNT	197	295	385	316	604	427
1	4	CNT	327	193	375	310	665	484
3	5	CNT	191	144	310	227	598	408
12	6	CNT	238	140	331	249	503	373
10	7	CNT	50	193	443	227	581	391
6	8	CNT	97	208	389	230	545	376
2	1	AB	247	436	471	406	651	500
11	2	AB	217	388	510	406	632	493
13	3	AB	234	378	467	387	571	458
9	4	AB	287	238	387	315	658	482
4	5	AB	313	231	436	341	590	462
13	6	AB	266	207	381	297	562	426
11	7	AB	58	215	389	221	646	418
14	8	AB	97	223	348	223	616	405
8	1	TUM	242	423	456	394	614	479
3	2	TUM	272	348	451	380	590	461
6	3	TUM	262	277	360	315	560	409
8	4	TUM	261	229	414	315	566	438
10	5	TUM	207	178	397	277	613	441
6	6	TUM	253	155	316	252	553	399
3	7	TUM	54	223	363	214	547	368
12	8	TUM	45	170	367	193	597	380
1	1	CUR	227	408	471	394	684	506
10	2	CUR	275	307	442	366	638	471
5	3	CUR	277	328	389	346	612	448
2	4	CUR	256	174	475	323	662	489
11	5	CUR	262	168	470	322	612	463
5	6	CUR	300	144	378	289	564	423
5	7	CUR	76	268	464	269	601	423
13	8	CUR	39	229	412	227	552	378

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 3. Pen means for ADFI

			ADFI, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
9	1	CNT	297	577	805	621	1124	814
4	2	CNT	331	508	896	655	1341	918
12	3	CNT	252	438	614	479	1007	682
1	4	CNT	339	376	646	475	1172	815
3	5	CNT	274	295	490	368	1031	692
12	6	CNT	272	280	525	378	908	637
10	7	CNT	134	355	744	390	1101	698
6	8	CNT	164	319	600	359	908	614
2	1	AB	325	587	721	588	1114	790
11	2	AB	330	564	829	638	1149	835
13	3	AB	280	476	711	544	1073	748
9	4	AB	353	382	763	529	1214	863
4	5	AB	329	410	646	481	1097	782
13	6	AB	296	308	567	410	955	676
11	7	AB	145	342	615	366	1007	635
14	8	AB	145	321	594	352	948	628
8	1	TUM	310	552	746	588	1032	759
3	2	TUM	330	554	779	610	1041	776
6	3	TUM	285	443	634	499	1087	725
8	4	TUM	319	348	645	460	1242	842
10	5	TUM	274	289	620	420	1064	734
6	6	TUM	270	270	524	374	926	644
3	7	TUM	125	310	533	322	874	578
12	8	TUM	166	321	572	352	939	624
1	1	CUR	295	554	726	575	1181	808
10	2	CUR	358	471	709	562	899	692
5	3	CUR	287	489	694	541	1142	772
2	4	CUR	326	350	653	466	1294	870
11	5	CUR	296	295	607	423	1042	719
5	6	CUR	317	289	574	415	1003	702
5	7	CUR	158	376	687	390	1004	656
13	8	CUR	134	336	652	372	921	627

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 4. Pen means for G:F

			G:F					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
9	1	CNT	0.822	0.672	0.632	0.664	0.578	0.619
4	2	CNT	0.649	0.720	0.533	0.586	0.506	0.542
12	3	CNT	0.780	0.672	0.628	0.658	0.600	0.625
1	4	CNT	0.967	0.513	0.581	0.654	0.567	0.593
3	5	CNT	0.698	0.487	0.632	0.616	0.580	0.590
12	6	CNT	0.875	0.500	0.631	0.660	0.554	0.586
10	7	CNT	0.371	0.543	0.596	0.582	0.528	0.560
6	8	CNT	0.592	0.651	0.647	0.641	0.600	0.613
2	1	AB	0.760	0.742	0.654	0.691	0.585	0.633
11	2	AB	0.656	0.688	0.616	0.637	0.550	0.591
13	3	AB	0.838	0.794	0.658	0.711	0.532	0.612
9	4	AB	0.813	0.622	0.507	0.595	0.542	0.559
4	5	AB	0.951	0.562	0.674	0.708	0.538	0.592
13	6	AB	0.896	0.671	0.673	0.724	0.588	0.630
11	7	AB	0.403	0.630	0.632	0.602	0.642	0.659
14	8	AB	0.672	0.694	0.585	0.633	0.649	0.644
8	1	TUM	0.780	0.767	0.611	0.670	0.595	0.631
3	2	TUM	0.824	0.627	0.579	0.623	0.566	0.594
6	3	TUM	0.920	0.625	0.569	0.631	0.515	0.564
8	4	TUM	0.817	0.658	0.642	0.684	0.456	0.520
10	5	TUM	0.757	0.614	0.640	0.660	0.576	0.601
6	6	TUM	0.934	0.573	0.603	0.674	0.597	0.620
3	7	TUM	0.431	0.720	0.680	0.663	0.627	0.638
12	8	TUM	0.273	0.529	0.642	0.549	0.636	0.609
1	1	CUR	0.769	0.736	0.649	0.686	0.579	0.626
10	2	CUR	0.768	0.652	0.623	0.652	0.710	0.681
5	3	CUR	0.965	0.670	0.561	0.639	0.536	0.580
2	4	CUR	0.786	0.497	0.728	0.694	0.511	0.561
11	5	CUR	0.885	0.571	0.774	0.760	0.587	0.645
5	6	CUR	0.944	0.497	0.658	0.697	0.562	0.603
5	7	CUR	0.479	0.711	0.675	0.690	0.598	0.644
13	8	CUR	0.290	0.680	0.632	0.609	0.599	0.602

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 5. Pen means for activity score for LPS challenge

			Activity Score				
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H12**	**H24**
1	1	CNT	5	3	2	4	5
3	2	CNT	5	3	2	3	5
12	3	CNT	5	3	3	4	5
9	1	AB	5	3	1	3	5
4	2	AB	5	3	3	4	5
13	3	AB	5	2	1	3	4
8	1	TUM	5	3	2	3	5
10	2	TUM	5	3	1	3	5
6	3	TUM	5	3	2	3	5
2	1	CUR	5	3	2	3	5
11	2	CUR	5	4	2	2	5
5	3	CUR	5	3	2	3	5

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 6. Pen means for % BW loss from h 0 for LPS challenge

			% BW loss from h 0			
Pen	**Rep**	**Trt**	**H3**	**H6**	**H12**	**H24**
9	1	CNT	99.5	98.4	95.1	92.9
4	2	CNT	99.3	97.4	96.7	99.3
12	3	CNT	98.1	97.2	98.1	100.9
1	4	CNT	96.2	95.4	92.4	96.2
3	5	CNT	96.7	95.0	96.7	100.0
12	6	CNT	95.9	95.9	95.9	102.0
2	1	AB	96.6	94.3	94.3	92.6
11	2	AB	96.8	96.2	93.7	96.2
13	3	AB	93.3	92.6	91.4	89.6
9	4	AB	98.0	98.0	97.0	99.0
4	5	AB	92.6	92.6	94.1	99.3
13	6	AB	94.7	92.9	95.6	99.1
8	1	TUM	97.1	96.7	97.1	94.7
3	2	TUM	96.1	94.2	94.2	94.8
6	3	TUM	94.3	93.7	93.7	97.5
8	4	TUM	94.4	95.2	92.0	96.8
10	5	TUM	95.9	93.8	97.3	97.9
6	6	TUM	93.3	92.4	95.2	101.0
1	1	CUR	97.2	97.2	97.7	96.6
10	2	CUR	97.4	98.7	100.0	101.3
5	3	CUR	97.7	98.3	98.3	101.7
2	4	CUR	95.9	94.5	95.9	95.9
11	5	CUR	96.0	96.0	98.0	101.0
5	6	CUR	97.8	97.1	97.8	100.7

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 7. Pen means for rectal temperature and changes in rectal temperature for LPS challenge

			Rectal Temperature, °C					Changes in Rectal Temperature			
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H12**	**H24**	**H3**	**H6**	**H12**	**H24**
9	1	CNT	39.1	41.4	41.7	40.1	40.1	2.28	2.55	0.94	0.94
4	2	CNT	39.7	41.0	40.2	40.5	39.5	1.22	0.50	0.72	-0.22
12	3	CNT	39.6	41.1	41.0	41.2	39.6	1.50	1.39	1.67	0.00
1	4	CNT	39.5	40.7	41.0	40.8	39.2	1.22	1.44	1.28	-0.33
3	5	CNT	39.8	42.2	41.5	39.8	39.3	2.39	1.67	0.00	-0.50
12	6	CNT	39.3	41.8	41.5	39.7	39.2	2.50	2.22	0.44	-0.11
2	1	AB	39.6	41.8	41.0	41.3	40.2	2.16	1.33	1.72	0.61
11	2	AB	39.7	41.1	40.4	40.3	39.6	1.33	0.67	0.61	-0.17
13	3	AB	39.8	41.1	40.3	41.2	40.3	1.28	0.56	1.44	0.56
9	4	AB	39.7	41.5	40.7	40.8	39.4	1.72	1.00	1.11	-0.33
4	5	AB	39.7	41.7	41.3	39.7	39.2	2.05	1.67	0.00	-0.44
13	6	AB	39.7	41.8	41.3	41.2	39.5	2.16	1.67	1.50	-0.22
8	1	TUM	40.1	41.5	40.8	41.5	39.8	1.44	0.78	1.39	-0.22
3	2	TUM	40.1	41.5	40.6	40.2	39.7	1.39	0.56	0.17	-0.33
6	3	TUM	40.0	40.7	41.3	41.0	39.5	0.72	1.33	0.94	-0.56
8	4	TUM	39.7	40.4	41.6	40.0	39.3	0.72	1.89	0.28	-0.39
10	5	TUM	39.3	42.0	41.2	39.9	39.3	2.66	1.83	0.56	0.00
6	6	TUM	39.8	41.3	41.0	40.1	39.3	1.50	1.17	0.28	-0.50
1	1	CUR	40.0	40.9	40.3	39.6	39.7	0.89	0.28	-0.44	-0.33
10	2	CUR	40.0	41.5	40.4	40.7	39.7	1.44	0.39	0.72	-0.28
5	3	CUR	40.3	41.8	40.2	40.5	40.3	1.50	-0.11	0.17	0.00
2	4	CUR	39.7	41.8	41.3	40.4	39.4	2.05	1.61	0.67	-0.33
11	5	CUR	39.6	41.9	41.1	41.0	39.5	2.33	1.50	1.39	-0.06
5	6	CUR	39.7	42.1	40.9	40.5	39.4	2.39	1.22	0.83	-0.28

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 8. Pig means for TNF-α and changes in TNF-α for LPS challenge

			TNF-α, pg/mL				Changes in TNF-α		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9	1	CNT	128	5652	1400	158	5524	1273	30.6
4	2	CNT	128	2825	818	107	2697	691	-20.7
12	3	CNT	52.4	3436	834	70.0	3384	781	17.6
1	4	CNT	60.5	5747	1413	96.2	5686	1353	35.7
3	5	CNT	164	6266	1500	160	6103	1337	-3.1
12	6	CNT	129	6462	1500	111	6333	1371	-17.8
2	1	AB	91.4	5652	1382	60.9	5560	1291	-30.5
11	2	AB	76.2	2646	790	87.7	2569	714	11.4
13	3	AB	64.9	1231	1122	87.6	1166	1057	22.7
9	4	AB	196	3515	1370	167	3319	1174	-29.0
4	5	AB	312	5886	1500	138	5574	1188	-174
13	6	AB	88.6	3819	1016	126	3730	927	37.1
8	1	TUM	36.0	3174	1049	142	3137	1013	105
3	2	TUM	47.2	3614	1086	142	3567	1038	94.3
6	3	TUM	88.9	4949	1321	132	4860	1232	43.4
8	4	TUM	118	7500	1500	263	7382	1382	145
10	5	TUM	124	7500	1500	184	7376	1376	59.2
6	6	TUM	102	5109	1500	165	5007	1398	63.1
1	1	CUR	40.5	1609	618	90.5	1568	577	49.9
10	2	CUR	67.3	1396	526	74.4	1328	459	7.1
5	3	CUR	101	3340	1073	126	3239	972	24.7
2	4	CUR	105	3236	1150	122	3131	1045	17.2
11	5	CUR	214	3999	1408	154	3785	1195	-60.0
5	6	CUR	97.4	3210	1015	93.7	3113	918	-3.6

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 9. Pig means for CRP and changes in CRP for LPS challenge

			CRP, mg/mL				Changes in CRP		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9	1	CNT	0.70	0.80	1.10	2.80	0.10	0.40	2.10
4	2	CNT	0.60	0.65	1.20	2.70	0.05	0.60	2.10
12	3	CNT	0.25	0.45	0.75	3.50	0.20	0.50	3.25
1	4	CNT	0.30	0.35	0.65	0.75	0.05	0.35	0.45
3	5	CNT	0.75	0.65	0.85	1.55	-0.10	0.10	0.80
12	6	CNT	0.65	0.65	1.15	1.40	0.00	0.50	0.75
2	1	AB	0.85	0.80	1.10	3.45	-0.05	0.25	2.60
11	2	AB	0.45	0.55	1.10	3.60	0.10	0.65	3.15
13	3	AB	2.40	2.40	2.90	4.85	0.00	0.50	2.45
9	4	AB	0.40	0.35	0.80	5.05	-0.05	0.40	4.65
4	5	AB	0.50	0.85	1.20	2.05	0.35	0.70	1.55
13	6	AB	0.70	0.50	0.90	2.30	-0.20	0.20	1.60
8	1	TUM	0.90	0.95	1.40	5.00	0.05	0.50	4.10
3	2	TUM	0.90	1.15	1.40	3.05	0.25	0.50	2.15
6	3	TUM	1.10	1.15	1.50	2.55	0.05	0.40	1.45
8	4	TUM	0.40	0.30	0.45	3.75	-0.10	0.05	3.35
10	5	TUM	1.75	1.55	1.80	2.25	-0.20	0.05	0.50
6	6	TUM	0.60	0.80	1.80	2.25	0.20	1.20	1.65
1	1	CUR	3.20	2.70	4.15	4.10	-0.50	0.95	0.90
10	2	CUR	1.25	1.30	2.00	4.25	0.05	0.75	3.00
5	3	CUR	1.25	1.10	1.45	3.15	-0.15	0.20	1.90
2	4	CUR	0.85	0.70	0.95	2.45	-0.15	0.10	1.60
11	5	CUR	0.20	0.25	0.45	2.80	0.05	0.25	2.60
5	6	CUR	0.50	0.65	1.10	3.30	0.15	0.60	2.80

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 10. Pig means for BUN and changes in BUN for LPS challenge

			BUN, mg/dL				Changes in BUN		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9	1	CNT	3.0	3.5	7.0	16.5	0.5	4.0	13.5
4	2	CNT	6.0	5.0	6.0	6.5	-1.0	0.0	0.5
12	3	CNT	6.0	7.0	7.0	12.5	1.0	1.0	6.5
1	4	CNT	9.0	9.0	10.5	10.5	0.0	1.5	1.5
3	5	CNT	6.0	7.0	10.0	11.0	1.0	4.0	5.0
12	6	CNT	5.5	4.0	5.0	7.0	-1.5	-0.5	1.5
2	1	AB	5.0	5.5	8.0	11.0	0.5	3.0	6.0
11	2	AB	6.0	6.0	9.0	10.0	0.0	3.0	4.0
13	3	AB	5.0	7.0	11.5	18.5	2.0	6.5	13.5
9	4	AB	4.0	9.0	5.0	8.0	5.0	1.0	4.0
4	5	AB	11.0	13.0	12.5	9.0	2.0	1.5	-2.0
13	6	AB	3.5	4.0	8.0	7.0	0.5	4.5	3.5
8	1	TUM	4.0	5.0	6.5	13.0	1.0	2.5	9.0
3	2	TUM	5.0	6.5	10.0	12.0	1.5	5.0	7.0
6	3	TUM	7.0	6.5	7.0	14.5	-0.5	0.0	7.5
8	4	TUM	8.0	4.0	12.0	15.0	-4.0	4.0	7.0
10	5	TUM	9.0	10.0	13.5	13.5	1.0	4.5	4.5
6	6	TUM	8.0	8.5	11.0	9.0	0.5	3.0	1.0
1	1	CUR	6.0	6.0	8.0	17.0	0.0	2.0	11.0
10	2	CUR	5.0	6.0	6.5	6.0	1.0	1.5	1.0
5	3	CUR	5.0	6.5	11.5	7.0	1.5	6.5	2.0
2	4	CUR	8.0	8.0	8.0	8.0	0.0	0.0	0.0
11	5	CUR	4.0	4.5	5.0	9.0	0.5	1.0	5.0
5	6	CUR	5.0	4.0	5.0	8.0	-1.0	0.0	3.0

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 11. Pig means for glucose and changes in glucose for LPS challenge

			Glucose, mg/dL				Changes in Glucose		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9	1	CNT	109	92	54	62	-17.0	-54.5	-46.5
4	2	CNT	107	87	95	93	-19.5	-11.5	-13.5
12	3	CNT	84	78	87	86	-6.0	3.5	2.0
1	4	CNT	105	88	84	88	-17.0	-21.5	-17.0
3	5	CNT	96	107	69	99	11.0	-27.0	2.5
12	6	CNT	95	99	73	96	3.5	-22.0	0.5
2	1	AB	111	63	81	119	-48.0	-29.5	8.5
11	2	AB	118	60	80	107	-58.5	-38.0	-11.5
13	3	AB	116	93	86	101	-23.5	-30.5	-15.5
9	4	AB	90	67	68	72	-22.5	-22.0	-18.0
4	5	AB	114	102	86	98	-12.0	-28.0	-16.0
13	6	AB	105	47	65	86	-58.0	-40.5	-19.5
8	1	TUM	116	100	85	124	-16.0	-31.0	8.0
3	2	TUM	109	88	68	115	-21.5	-41.0	5.5
6	3	TUM	142	50	101	116	-91.5	-41.0	-25.5
8	4	TUM	95	79	64	72	-16.0	-31.0	-23.5
10	5	TUM	91	59	66	98	-31.5	-25.0	7.0
6	6	TUM	87	91	58	84	4.0	-29.0	-3.0
1	1	CUR	123	105	68	112	-18.5	-55.0	-11.0
10	2	CUR	115	104	102	107	-11.0	-13.0	-8.0
5	3	CUR	115	94	73	111	-21.0	-42.0	-3.5
2	4	CUR	88	101	84	91	12.5	-4.0	3.0
11	5	CUR	95	82	73	92	-13.0	-22.0	-3.0
5	6	CUR	131	101	67	107	-30.0	-63.5	-23.5

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 12. Pig means for total protein and changes in total protein for LPS challenge

			Total Protein, g/dL				Changes in Total Protein		
Pen	Rep	Trt	H0	H3	H6	H24	H3	H6	H24
9	1	CNT	5.3	4.1	4.4	5.4	-1.15	-0.85	0.15
4	2	CNT	4.6	4.0	3.9	5.1	-0.60	-0.70	0.50
12	3	CNT	4.4	4.0	4.0	4.6	-0.45	-0.45	0.20
1	4	CNT	4.0	5.6	3.8	3.5	1.65	-0.15	-0.50
3	5	CNT	3.4	3.6	5.6	3.7	0.20	2.25	0.35
12	6	CNT	5.0	3.8	3.6	4.5	-1.20	-1.40	-0.55
2	1	AB	4.5	4.2	4.1	4.8	-0.35	-0.40	0.30
11	2	AB	4.9	4.5	3.6	5.1	-0.35	-1.30	0.25
13	3	AB	4.7	4.3	3.9	5.0	-0.40	-0.80	0.25
9	4	AB	3.8	3.2	4.8	4.1	-0.60	0.95	0.25
4	5	AB	3.5	3.4	4.8	3.1	-0.10	1.35	-0.35
13	6	AB	5.8	3.2	2.6	3.1	-2.55	-3.20	-2.70
8	1	TUM	4.8	4.2	4.1	5.1	-0.55	-0.65	0.30
3	2	TUM	4.8	4.1	3.9	4.9	-0.70	-0.90	0.15
6	3	TUM	4.3	3.9	4.1	4.9	-0.35	-0.15	0.60
8	4	TUM	3.6	3.6	5.0	3.4	-0.05	1.40	-0.25
10	5	TUM	4.3	3.8	3.6	4.7	-0.55	-0.75	0.35
6	6	TUM	4.5	4.8	4.3	4.5	0.30	-0.20	-0.05
1	1	CUR	5.0	3.9	3.9	4.5	-1.10	-1.15	-0.50
10	2	CUR	4.6	4.4	3.6	4.9	-0.15	-0.95	0.35
5	3	CUR	4.7	4.3	4.2	4.7	-0.45	-0.55	-0.05
2	4	CUR	5.2	5.0	3.8	3.9	-0.20	-1.40	-1.30
11	5	CUR	4.4	4.3	3.4	4.7	-0.05	-0.95	0.30
5	6	CUR	5.3	4.3	3.6	4.9	-0.95	-1.65	-0.35

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 13. Pig means for triglycerides and changes in triglycerides for LPS challenge

			Triglycerides, mg/mL				Changes in Triglycerides		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9	1	CNT	31	40	41	117	9.0	10.0	85.5
4	2	CNT	12	19	18	21	7.5	6.5	9.0
12	3	CNT	32	38	24	16	6.0	-8.0	-16.5
1	4	CNT	25	38	20	19	13.0	-5.0	-6.0
3	5	CNT	14	18	16	17	4.5	2.0	3.5
12	6	CNT	34	46	18	39	12.0	-16.0	4.5
2	1	AB	22	31	38	30	9.5	16.5	8.0
11	2	AB	13	17	27	30	4.0	14.0	17.0
13	3	AB	44	50	50	98	6.0	6.5	54.5
9	4	AB	47	30	34	58	-17.0	-13.0	11.0
4	5	AB	21	50	22	30	29.5	1.0	9.0
13	6	AB	16	26	27	27	10.0	10.5	11.0
8	1	TUM	24	14	20	69	-9.5	-4.0	45.5
3	2	TUM	37	48	59	52	10.5	21.5	14.5
6	3	TUM	42	24	29	48	-17.5	-12.5	6.5
8	4	TUM	27	41	17	26	14.0	-10.0	-1.0
10	5	TUM	22	34	39	32	11.5	16.5	10.0
6	6	TUM	42	77	28	73	35.0	-14.0	30.5
1	1	CUR	21	48	71	18	26.5	50.0	-3.0
10	2	CUR	20	18	16	16	-2.0	-4.0	-4.0
5	3	CUR	34	37	54	38	2.5	19.5	3.5
2	4	CUR	53	53	33	21	0.0	-20.0	-32.5
11	5	CUR	37	40	15	48	3.0	-21.5	11.5
5	6	CUR	29	28	25	28	-1.5	-4.5	-1.0

CNT = control diet containing no antibiotics
AB = 55 mg/kg of carbadox
TUM = control diet + 2 g/kg of turmeric powder
CUR = control diet + 80 mg/kg of curcumin powder

Appendix 2 Table 14. Analysis of variance for BW

		Mean square				
Source	**df**	**D0**	**D7**	**D14**	**D21**	**D42**
Total	31					
Rep	7	4.50057169	6.72108639	8.87073631	25.4198488	24.4116151
Trt	3	0.00098359	0.05057365	0.32034229	1.1172591	3.6906873
Error	21	0.00318182	0.05510331	0.09448951	0.2848702	0.4388202
CV, %		0.98	3.30	3.50	4.17	2.78

Appendix 2 Table 15. Analysis of variance for ADG

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	31						
Rep	7	0.03125765	0.03344409	0.00714249	0.01776913	0.00498382	0.00680063
Trt	3	0.00081528	0.00364219	0.00354998	0.00204513	0.00226275	0.00194625
Error	21	0.00108518	0.00068318	0.00154811	0.00051124	0.00094783	0.00023701
CV, %		16.01	10.12	9.51	7.36	5.10	3.50

Appendix 2 Table 16. Analysis of variance for ADFI

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	31						
Rep	7	0.02368185	0.04352905	0.02827206	0.03985858	0.03891131	0.02682061
Trt	3	0.00058490	0.00221539	0.00339259	0.00171937	0.00384315	0.00164516
Error	21	0.00027193	0.00077161	0.00354407	0.00086129	0.00742568	0.00214879
CV, %		6.20	6.95	9.02	6.26	8.15	6.35

Appendix 2 Table 17. Analysis of variance for G:F

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	31						
Rep	7	0.14251928	0.01655660	0.00324115	0.00355730	0.00388676	0.00191442
Trt	3	0.00174732	0.00886183	0.00416776	0.00322159	0.00066509	0.00139117
Error	21	0.01120704	0.00397962	0.00234067	0.00141319	0.00213754	0.00100132
CV, %		14.50	9.95	7.68	5.74	8.04	5.23

Appendix 2 Table 18. Fixed effects for activity score for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	38	0.99	0.4059
Hr	4	38	120.15	<0.0001
Trt x Hr	12	38	1.39	0.2116

Appendix 2 Table 19. Analysis of variance for % BW loss from h 0 for LPS challenge

		Mean square			
Source	df	H3	H6	H12	H24
Total	23				
Rep	5	5.05183242	3.60432187	5.97158626	20.0318352
Trt	3	8.70585647	11.30657489	14.94646567	14.9078681
Error	15	1.60712953	2.52131498	2.4869982	6.7385126
CV, %		1.32	1.66	1.65	2.64

Appendix 2 Table 20. Fixed effects for rectal temperature for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	95	0.51	0.6777
Hr	4	95	78.22	<0.0001
Trt x Hr	12	95	1.07	0.3906

Appendix 2 Table 21. Fixed effects for changes in rectal temperature for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	95	1.74	0.1680
Hr	4	95	72.49	<0.0001
Trt x Hr	12	95	1.06	0.3977

Appendix 2 Table 22. Fixed effects for TNF-α for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	5.13	0.0028
Hr	3	75	164.35	<0.0001
Trt x Hr	9	75	3.42	0.0014

Appendix 2 Table 23. Fixed effects for changes in TNF-α for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	5.56	0.0017
Hr	3	75	165.69	<0.0001
Trt x Hr	9	75	3.44	0.0014

Appendix 2 Table 24. Fixed effects for CRP for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	2.64	0.0554
Hr	3	75	68.31	<0.0001
Trt x Hr	9	75	0.96	0.4819

Appendix 2 Table 25. Fixed effects for changes in CRP for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	0.89	0.4517
Hr	3	75	74.10	<0.0001
Trt x Hr	9	75	0.91	0.5224

Appendix 2 Table 26. Fixed effects for BUN for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	1.59	0.2000
Hr	3	75	18.51	<0.0001
Trt x Hr	9	75	0.53	0.8453

Appendix 2 Table 27. Fixed effects for changes in BUN for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	0.58	0.6326
Hr	3	75	20.43	<0.0001
Trt x Hr	9	75	0.57	0.8210

Appendix 2 Table 28. Fixed effects for glucose for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	1.68	0.1786
Hr	3	75	21.03	<0.0001
Trt x Hr	9	75	1.63	0.1234

Appendix 2 Table 29. Fixed effects for changes in glucose for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	1.14	0.3377
Hr	3	75	22.53	<0.0001
Trt x Hr	9	75	1.87	0.0699

Appendix 2 Table 30. Fixed effects for total protein for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	0.97	0.4115
Hr	3	75	4.32	0.0073
Trt x Hr	9	75	0.67	0.7369

Appendix 2 Table 31. Fixed effects for changes in total protein for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	1.09	0.3592
Hr	3	75	3.78	0.0140
Trt x Hr	9	75	0.66	0.7428

Appendix 2 Table 32. Fixed effects for triglycerides for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	0.57	0.6384
Hr	3	75	2.97	0.0372
Trt x Hr	9	75	0.76	0.6493

Appendix 2 Table 33. Fixed effects for changes in triglycerides for LPS challenge

Effect	Num df	Den df	F value	Pr > F
Trt	3	75	0.70	0.5527
Hr	3	75	3.20	0.0282
Trt x Hr	9	75	0.88	0.5474

APPENDIX 3

EXPERIMENT 3

Appendix 3 Table 1. Pig means for curcumin intake (Exp. 1)

			Intake, mg/kg of BW/d
Pen	**Rep**	**Trt**	**Curcumin**
8	1	AB	0.00
4	2	AB	0.00
5	3	AB	0.00
1	4	AB	0.00
10	5	AB	0.00
13	6	AB	0.00
9	1	20	0.77
3	2	20	0.76
12	3	20	0.76
9	4	20	0.70
11	5	20	0.81
6	6	20	0.78
1	1	40	1.47
10	2	40	1.47
6	3	40	1.63
2	4	40	1.41
3	5	40	1.26
5	6	40	1.33
2	1	80	3.03
11	2	80	3.25
13	3	80	3.18
8	4	80	2.75
4	5	80	2.93
12	6	80	2.91

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 2. Pen means for BW (Exp. 1)

			BW, kg				
Pen	**Rep**	**Trt**	**D0**	**D7**	**D14**	**D21**	**D42**
8	1	AB	7.2	7.7	9.0	12.1	27.4
4	2	AB	6.3	6.8	8.6	11.8	26.6
5	3	AB	5.0	6.0	8.1	11.8	25.8
1	4	AB	7.3	7.1	8.3	10.4	25.3
10	5	AB	6.4	6.6	8.1	11.0	25.4
13	6	AB	5.4	5.8	7.4	10.0	21.9
9	1	20	7.1	7.7	9.4	12.7	27.5
3	2	20	6.1	6.8	8.5	11.6	26.1
12	3	20	5.1	5.9	7.3	10.8	24.7
9	4	20	7.2	7.1	8.6	11.7	25.6
11	5	20	6.4	6.8	8.9	11.5	26.5
6	6	20	5.3	5.9	7.3	10.0	22.3
1	1	40	7.1	7.4	9.1	11.4	27.2
10	2	40	6.1	7.0	8.5	11.6	26.2
6	3	40	5.1	5.8	7.7	10.8	25.1
2	4	40	7.3	7.7	9.7	12.6	27.7
3	5	40	6.3	6.6	7.8	9.6	19.3
5	6	40	5.4	5.9	7.2	9.7	23.3
2	1	80	7.2	7.5	8.9	11.6	25.6
11	2	80	6.1	6.6	8.0	10.7	25.0
13	3	80	5.0	5.7	7.8	11.0	25.1
8	4	80	7.3	7.6	9.6	12.5	27.0
4	5	80	6.4	6.7	8.2	11.1	24.3
12	6	80	5.4	5.9	7.6	10.7	23.6

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 3. Pen means for ADG (Exp. 1)

			ADG, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
8	1	AB	60	178	191	212	762	468
4	2	AB	73	203	250	241	742	474
5	3	AB	123	182	305	296	698	483
1	4	AB	-26	159	167	156	706	419
10	5	AB	33	171	205	209	685	436
13	6	AB	54	194	239	202	566	376
9	1	20	70	191	237	242	738	473
3	2	20	87	194	235	240	720	463
12	3	20	97	178	209	245	694	454
9	4	20	-26	165	217	193	662	417
11	5	20	58	230	301	223	713	457
6	6	20	80	216	207	206	582	385
1	1	40	36	174	241	187	790	468
10	2	40	118	196	213	243	733	471
6	3	40	86	186	274	248	713	465
2	4	40	50	200	287	230	719	464
3	5	40	48	182	165	142	466	296
5	6	40	72	218	189	187	625	396
1	1	80	34	160	202	193	696	427
11	2	80	63	205	196	199	715	439
13	3	80	89	181	291	259	704	466
8	4	80	46	184	278	228	689	448
4	5	80	48	216	215	206	628	407
12	6	80	80	194	242	231	633	423

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 4. Pen means for ADFI (Exp. 1)

			ADFI, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
8	1	AB	178	191	340	409	1281	814
4	2	AB	203	250	362	405	1463	897
5	3	AB	182	305	368	413	1326	838
1	4	AB	159	167	237	326	1502	794
10	5	AB	171	205	292	361	1354	799
13	6	AB	194	239	312	378	896	625
9	1	20	191	237	395	426	1340	851
3	2	20	194	235	335	395	1207	773
12	3	20	178	209	335	361	1151	707
9	4	20	165	217	271	361	1126	726
11	5	20	230	301	401	417	1317	846
6	6	20	216	207	320	397	996	683
1	1	40	174	241	355	400	1234	788
10	2	40	196	213	378	393	1220	753
6	3	40	186	274	383	402	1188	767
2	4	40	200	287	350	403	1212	789
3	5	40	182	165	282	318	778	538
5	6	40	218	189	286	380	854	591
1	1	80	160	202	330	364	1288	794
11	2	80	205	196	347	369	1275	791
13	3	80	181	291	355	390	1160	748
8	4	80	184	278	338	395	1159	760
4	5	80	216	215	292	383	1084	718
12	6	80	194	242	305	378	1007	666

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 5. Pen means for G:F (Exp. 1)

			G:F					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
8	1	AB	0.336	0.561	0.549	0.520	0.595	0.575
4	2	AB	0.359	0.691	0.623	0.595	0.507	0.528
5	3	AB	0.676	0.829	0.674	0.716	0.526	0.576
1	4	AB	-0.163	0.703	0.547	0.480	0.470	0.527
10	5	AB	0.195	0.705	0.613	0.578	0.506	0.546
13	6	AB	0.276	0.766	0.506	0.535	0.631	0.601
9	1	20	0.364	0.600	0.611	0.569	0.551	0.556
3	2	20	0.450	0.702	0.612	0.607	0.597	0.600
12	3	20	0.545	0.624	0.712	0.679	0.603	0.642
9	4	20	-0.157	0.799	0.590	0.534	0.588	0.574
11	5	20	0.253	0.751	0.507	0.536	0.541	0.540
6	6	20	0.369	0.647	0.505	0.518	0.584	0.564
1	1	40	0.205	0.677	0.438	0.468	0.641	0.594
10	2	40	0.603	0.564	0.632	0.619	0.601	0.626
6	3	40	0.461	0.715	0.614	0.619	0.600	0.606
2	4	40	0.250	0.820	0.544	0.572	0.593	0.588
3	5	40	0.264	0.584	0.436	0.446	0.598	0.551
5	6	40	0.332	0.660	0.474	0.492	0.731	0.670
1	1	80	0.213	0.611	0.576	0.531	0.540	0.538
11	2	80	0.308	0.565	0.612	0.540	0.561	0.556
13	3	80	0.493	0.818	0.638	0.664	0.606	0.623
8	4	80	0.251	0.822	0.548	0.577	0.594	0.589
4	5	80	0.223	0.734	0.549	0.536	0.579	0.567
12	6	80	0.410	0.794	0.589	0.611	0.628	0.635

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 6. Pen means for activity score for LPS challenge (Exp. 1)

			Activity Score				
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H12**	**H24**
8	1	AB	5.0	2.0	2.0	4.0	5.0
4	2	AB	5.0	1.5	2.5	4.5	5.0
5	3	AB	5.0	1.5	2.0	3.5	4.5
1	4	AB	5.0	3.0	0.0	.	.
10	5	AB	5.0	2.0	2.0	1.5	5.0
13	6	AB	5.0	2.5	2.0	3.5	5.0
9	1	20	5.0	1.5	2.0	4.0	4.5
3	2	20	5.0	1.5	3.0	5.0	5.0
12	3	20	5.0	2.0	2.5	4.0	4.0
9	4	20	5.0	2.0	2.0	3.5	4.5
11	5	20	5.0	2.0	1.5	3.0	4.5
6	6	20	5.0	3.0	1.5	4.0	5.0
1	1	40	5.0	2.5	2.5	5.0	5.0
10	2	40	5.0	1.5	2.0	3.0	4.5
6	3	40	4.5	2.0	2.5	3.5	5.0
2	4	40	5.0	2.5	3.0	3.5	4.5
3	5	40	5.0	3.0	3.0	3.5	5.0
5	6	40	5.0	2.0	1.0	4.0	5.0
2	1	80	5.0	2.0	3.0	5.0	5.0
11	2	80	5.0	1.5	2.5	3.0	5.0
13	3	80	5.0	1.5	3.0	3.0	4.5
8	4	80	5.0	2.5	1.5	3.5	5.0
4	5	80	5.0	2.0	2.5	3.5	5.0
12	6	80	5.0	2.5	1.0	3.5	5.0

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 7. Pen means for % BW loss from h 0 for LPS challenge (Exp. 1)

			% BW loss from h 0			
Pen	**Rep**	**Trt**	**H3**	**H6**	**H12**	**H24**
8	1	AB	96.9	95.3	100.5	102.1
4	2	AB	95.3	93.0	93.8	95.7
5	3	AB	96.5	95.1	95.8	97.5
1	4	AB	93.8	.	.	.
10	5	AB	93.7	93.2	84.7	91.0
13	6	AB	95.0	96.2	93.7	95.0
9	1	20	96.4	95.6	99.1	100.4
3	2	20	96.3	95.2	98.9	100.5
12	3	20	97.5	96.5	95.5	99.0
9	4	20	96.7	95.8	94.1	97.9
11	5	20	97.0	96.3	94.8	95.5
6	6	20	94.1	94.1	96.6	98.0
1	1	40	98.8	95.9	99.6	101.6
10	2	40	97.5	95.4	96.7	100.0
6	3	40	97.9	96.7	96.7	100.8
2	4	40	95.2	94.3	96.2	98.1
3	5	40	96.3	95.3	93.7	95.8
5	6	40	95.4	94.4	94.0	92.6
2	1	80	96.6	95.1	97.1	100.5
11	2	80	96.0	94.0	97.0	96.5
13	3	80	97.2	94.9	96.7	97.7
8	4	80	96.1	94.9	95.7	97.3
4	5	80	97.1	96.3	94.2	94.6
12	6	80	95.6	94.7	96.9	100.4

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 8. Pen means for rectal temperature and changes in rectal temperature for LPS challenge (Exp. 1)

			Rectal Temperature, °C					Changes in Rectal Temperature			
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H12**	**H24**	**H3**	**H6**	**H12**	**H24**
8	1	AB	39.6	41.2	40.2	40.0	39.4	1.61	0.64	0.44	-0.22
4	2	AB	39.4	41.4	40.8	40.2	39.6	2.00	1.39	0.83	0.22
5	3	AB	39.7	42.0	41.2	40.5	39.6	2.30	1.53	0.75	-0.08
1	4	AB	39.8	38.9	.	.	.	-0.92	.	.	.
10	5	AB	39.9	40.2	39.0	39.2	39.1	0.31	-0.89	-0.64	-0.75
13	6	AB	39.6	40.2	40.4	39.9	39.0	0.64	0.86	0.31	-0.61
9	1	20	39.5	41.3	40.8	40.4	39.3	1.78	1.33	0.89	-0.17
3	2	20	39.7	41.8	40.6	39.5	39.3	2.16	0.94	-0.19	-0.33
12	3	20	39.3	40.7	40.5	40.0	39.4	1.36	1.11	0.64	0.03
9	4	20	39.8	40.2	40.7	39.8	39.5	0.36	0.86	0.00	-0.36
11	5	20	39.6	41.2	41.0	40.0	39.4	1.58	1.36	0.42	-0.19
6	6	20	39.6	41.5	40.9	39.5	39.3	1.83	1.30	-0.08	-0.31
1	1	40	39.9	41.2	40.4	40.1	39.7	1.25	0.47	0.17	-0.22
10	2	40	39.8	41.6	40.9	40.8	39.6	1.80	1.11	1.00	-0.17
6	3	40	39.7	41.4	41.3	40.0	39.5	1.78	1.64	0.36	-0.11
2	4	40	39.2	39.7	38.7	39.2	39.0	0.53	-0.47	0.00	-0.17
3	5	40	39.0	41.4	40.8	39.3	39.0	2.36	1.75	0.22	-0.08
5	6	40	39.4	39.5	38.5	38.2	39.0	0.03	-0.89	-1.25	-0.39
2	1	80	39.8	41.7	41.0	40.4	39.7	1.89	1.19	0.58	-0.11
11	2	80	39.5	41.0	40.3	39.3	39.2	1.47	0.83	-0.17	-0.33
13	3	80	39.6	41.5	41.1	39.7	39.7	1.97	1.53	0.17	0.11
8	4	80	40.1	40.6	40.3	39.9	39.5	0.50	0.22	-0.19	-0.61
4	5	80	39.6	39.8	40.2	39.6	39.4	0.22	0.58	-0.03	-0.25
12	6	80	39.3	41.1	41.1	39.5	39.4	1.72	1.78	0.11	0.06

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 9. Pig means for TNF-α and changes in TNF-α for LPS challenge (Exp. 1)

			TNF-α, pg/mL				Changes in TNF-α		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
8	1	AB	92.5	5996	1811	91.3	5903	1718	-1.2
4	2	AB	83.5	5305	1375	113	5222	1291	29.5
5	3	AB	42.7	4432	1403	73.3	4390	1361	30.6
1	4	AB	108	46541	.	.	46433	.	.
10	5	AB	130	23547	2861	129	23417	2730	-1.0
13	6	AB	88.3	9642	2013	116	9554	1924	28.2
9	1	20	106	6357	1820	170	6251	1714	63.7
3	2	20	85.1	8009	2275	129	7924	2190	43.8
12	3	20	50.2	3498	1421	66.2	3448	1371	16.0
9	4	20	73.0	7417	2388	152	7344	2315	79.4
11	5	20	107	11959	3385	227	11852	3277	119
6	6	20	95.0	13779	3268	116	13684	3173	20.6
1	1	40	78.0	5246	1411	121	5168	1333	42.8
10	2	40	115	7117	1887	106	7001	1771	-9.8
6	3	40	49.9	2508	603	61.2	2458	553	11.3
2	4	40	153	12843	2702	227	12690	2549	74.2
3	5	40	.	7249	1964	91.3	.	.	.
5	6	40	88.1	19750	6870	408	19662	6782	320
2	1	80	80.2	6309	2057	128	6229	1977	47.9
11	2	80	86.2	12027	3618	215	11940	3532	129
13	3	80	54.3	4261	1802	101	4207	1747	47.1
8	4	80	129	18784	3532	417	18655	3403	288
4	5	80	.	14874	3654	229	.	.	.
12	6	80	117	7308	2166	116	7192	2050	-0.7

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 10. Pig means for CRP and changes in CRP for LPS challenge (Exp. 1)

			CRP, mg/mL				Changes in CRP		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
8	1	AB	1.98	2.00	1.63	3.90	0.03	-0.35	1.93
4	2	AB	1.23	1.23	1.70	3.80	0.00	0.48	2.58
5	3	AB	1.33	1.53	1.75	4.08	0.20	0.43	2.75
1	4	AB	0.68	0.73	.	.	0.05	.	.
10	5	AB	0.50	0.60	1.35	2.15	0.10	0.85	1.65
13	6	AB	0.43	1.05	1.33	1.95	0.63	0.90	1.53
9	1	20	0.45	0.55	0.95	4.48	0.10	0.50	4.03
3	2	20	0.73	0.58	1.13	2.30	-0.15	0.40	1.58
12	3	20	0.68	0.68	1.30	2.05	0.00	0.63	1.38
9	4	20	1.60	0.65	2.20	2.78	-0.95	0.60	1.18
11	5	20	0.65	0.95	1.65	3.45	0.30	1.00	2.80
6	6	20	0.95	2.08	2.05	2.58	1.13	1.10	1.63
1	1	40	1.30	1.18	1.43	2.10	-0.13	0.13	0.80
10	2	40	1.10	1.00	1.45	4.08	-0.10	0.35	2.98
6	3	40	0.60	0.65	1.08	2.05	0.05	0.48	1.45
2	4	40	0.15	0.20	0.40	2.35	0.05	0.25	2.20
3	5	40	0.91	0.80	0.70	1.85	-0.11	-0.21	0.94
5	6	40	1.90	1.35	1.85	2.85	-0.55	-0.05	0.95
2	1	80	0.78	0.60	1.00	4.10	-0.18	0.23	3.33
11	2	80	0.20	0.25	0.65	1.43	0.05	0.45	1.23
13	3	80	0.33	0.38	0.73	2.95	0.05	0.40	2.63
8	4	80	1.28	1.33	1.75	2.45	0.05	0.48	1.18
4	5	80	0.80	0.68	1.15	2.03	-0.13	0.35	1.23
12	6	80	2.05	1.00	1.38	2.35	-1.05	-0.68	0.30

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 11. Pig means for BUN and changes in BUN for LPS challenge (Exp. 1)

			BUN, mg/d				Changes in BUN		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
8	1	AB	7.5	7.5	9.0	8.8	0.0	1.5	1.3
4	2	AB	4.8	5.8	9.0	12.3	1.0	4.3	7.5
5	3	AB	5.0	5.3	7.5	10.8	0.3	2.5	5.8
1	4	AB	5.3	7.0	.	.	1.8	.	.
10	5	AB	7.0	5.0	2.5	6.0	-2.0	-4.5	-1.0
13	6	AB	3.8	3.8	5.0	12.0	0.0	1.3	8.3
9	1	20	4.0	4.3	5.5	9.0	0.3	1.5	5.0
3	2	20	3.0	3.5	6.8	5.0	0.5	3.8	2.0
12	3	20	6.0	6.0	8.0	11.5	0.0	2.0	5.5
9	4	20	4.0	5.0	5.8	9.3	1.0	1.8	5.3
11	5	20	4.0	3.5	5.0	17.8	-0.5	1.0	13.8
6	6	20	3.0	5.0	6.5	8.0	2.0	3.5	5.0
1	1	40	9.0	9.0	9.8	12.0	0.0	0.8	3.0
10	2	40	4.8	4.5	5.0	7.5	-0.3	0.3	2.8
6	3	40	6.0	5.5	6.8	10.0	-0.5	0.8	4.0
2	4	40	5.0	5.0	5.0	11.0	0.0	0.0	6.0
3	5	40	5.9	6.0	10.0	10.0	0.1	4.1	4.1
5	6	40	4.0	5.3	8.0	31.8	1.3	4.0	27.8
2	1	80	5.0	5.0	6.3	12.0	0.0	1.3	7.0
11	2	80	8.8	8.5	10.5	14.3	-0.3	1.8	5.5
13	3	80	6.3	7.3	8.5	8.5	1.0	2.3	2.3
8	4	80	4.5	5.0	8.3	15.5	0.5	3.8	11.0
4	5	80	6.1	4.5	6.0	16.3	-1.6	-0.1	10.1
12	6	80	6.0	4.3	6.0	8.3	-1.8	0.0	2.3

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 12. Pig means for glucose and changes in glucose for LPS challenge (Exp. 1)

			Glucose, mg/dL				Changes in Glucose		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
8	1	AB	100	83	77	101	-17.8	-23.5	0.3
4	2	AB	125	82	96	97	-43.5	-29.3	-28.8
5	3	AB	122	99	79	107	-23.5	-43.5	-15.0
1	4	AB	79	96	.	.	16.3	.	.
10	5	AB	90	88	69	98	-2.0	-21.0	8.5
13	6	AB	113	71	50	100	-41.8	-62.8	-12.8
9	1	20	101	87	76	96	-14.0	-25.5	-5.5
3	2	20	104	85	75	104	-18.8	-29.5	0.3
12	3	20	110	90	69	104	-20.0	-41.0	-6.5
9	4	20	93	80	60	102	-13.3	-33.0	8.8
11	5	20	102	109	64	91	7.5	-37.5	-10.3
6	6	20	111	77	65	85	-34.3	-46.0	-26.3
1	1	40	96	83	85	111	-13.5	-11.5	14.8
10	2	40	107	90	70	101	-16.5	-36.8	-6.3
6	3	40	119	105	96	122	-14.5	-23.0	3.0
2	4	40	94	84	56	75	-9.8	-38.0	-18.8
3	5	40	104	72	59	79	-32.5	-45.0	-25.5
5	6	40	105	74	19	81	-31.0	-85.5	-23.5
2	1	80	110	86	78	99	-23.3	-31.5	-10.8
11	2	80	97	94	50	101	-2.5	-46.8	4.8
13	3	80	99	103	85	150	3.3	-14.8	50.5
8	4	80	103	86	61	81	-16.8	-42.5	-22.3
4	5	80	104	85	62	88	-18.7	-41.7	-15.7
12	6	80	117	90	67	95	-27.3	-49.8	-21.8

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 13. Pig means for total protein and changes in total protein for LPS challenge (Exp. 1)

			Total Protein, g/dL				Changes in Total Protein		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
8	1	AB	5.7	5.3	4.9	5.0	-0.4	-0.7	-0.6
4	2	AB	4.9	4.5	4.2	4.6	-0.4	-0.7	-0.3
5	3	AB	4.9	4.3	4.2	4.6	-0.6	-0.7	-0.4
1	4	AB	4.4	3.7	.	.	-0.8	.	.
10	5	AB	4.8	3.6	3.6	4.0	-1.2	-1.2	-0.8
13	6	AB	4.7	4.1	3.7	3.9	-0.6	-1.0	-0.8
9	1	20	5.1	4.5	4.5	4.7	-0.6	-0.6	-0.5
3	2	20	5.2	4.2	4.4	4.3	-1.0	-0.9	-0.9
12	3	20	4.3	3.9	3.8	4.7	-0.5	-0.5	0.3
9	4	20	4.5	3.9	3.5	4.2	-0.6	-1.0	-0.3
11	5	20	5.2	4.5	4.3	4.4	-0.7	-0.9	-0.8
6	6	20	4.6	4.1	3.7	4.1	-0.5	-0.9	-0.5
1	1	40	5.2	4.7	4.5	5.0	-0.5	-0.7	-0.2
10	2	40	5.0	4.7	4.4	4.5	-0.3	-0.7	-0.5
6	3	40	4.7	4.1	4.2	4.8	-0.6	-0.6	0.1
2	4	40	5.4	4.1	4.5	4.7	-1.4	-1.0	-0.7
3	5	40	5.0	4.2	4.0	4.5	-0.8	-1.0	-0.5
5	6	40	4.0	3.5	3.5	3.6	-0.5	-0.5	-0.4
2	1	80	5.5	5.0	4.9	5.2	-0.5	-0.6	-0.3
11	2	80	4.9	4.3	4.1	4.4	-0.7	-0.9	-0.5
13	3	80	4.5	3.9	3.8	4.5	-0.6	-0.7	0.0
8	4	80	4.4	3.9	3.8	4.0	-0.5	-0.6	-0.4
4	5	80	4.8	3.6	3.3	3.9	-1.1	-1.5	-0.9
12	6	80	4.2	3.8	3.5	4.1	-0.4	-0.7	-0.1

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 14. Pig means for triglycerides and changes in triglycerides for LPS challenge (Exp. 1)

			Triglycerides, mg/mL				Changes in Triglycerides		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
8	1	AB	26	45	13	41	18.8	-12.8	14.8
4	2	AB	31	44	45	26	13.0	14.5	-4.3
5	3	AB	15	36	33	40	21.5	17.8	24.8
1	4	AB	26	66	.	.	40.0	.	.
10	5	AB	25	94	36	52	69.3	10.5	27.0
13	6	AB	27	29	20	35	2.5	-6.5	8.0
9	1	20	32	47	19	41	14.3	-13.8	8.3
3	2	20	32	56	18	41	24.0	-14.3	8.8
12	3	20	30	37	19	36	6.8	-10.8	6.3
9	4	20	23	38	19	26	14.8	-4.8	3.0
11	5	20	52	50	27	41	-1.8	-25.0	-10.3
6	6	20	21	22	14	27	1.5	-6.8	6.5
1	1	40	16	24	23	27	8.0	7.0	11.0
10	2	40	24	44	19	22	19.8	-5.3	-2.5
6	3	40	15	23	14	20	7.8	-1.5	5.0
2	4	40	51	52	25	40	0.3	-26.8	-11.5
3	5	40	27	60	27	39	33.4	0.6	12.1
5	6	40	28	61	48	45	33.5	20.0	17.5
2	1	80	34	38	16	35	3.8	-18.8	0.3
11	2	80	30	52	31	42	22.3	1.3	11.5
13	3	80	9	18	13	15	8.5	3.5	5.8
8	4	80	42	87	44	29	45.8	2.5	-13.0
4	5	80	27	32	24	68	4.9	-2.8	41.7
12	6	80	10	34	16	28	24.8	6.3	18.5

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 3 Table 15. Analysis of variance for curcumin intake (Exp. 1)

		Mean square
Source	**df**	**Curcumin**
Total	23	
Rep	5	0.02002256
Trt	3	9.82308922
Linear	1	29.43991189
Quadratic	1	0.01259112
AB vs. CUR	1	13.51475015
Error	15	0.01039899
CV, %		7.85

Appendix 3 Table 16. Analysis of variance for BW (Exp. 1)

		Mean square				
Source	**df**	**D0**	**D7**	**D14**	**D21**	**D42**
Total	23					
Rep	5	3.30484061	2.10381708	1.82491639	1.91038595	10.04071759
Trt	3	0.00224797	0.00484282	0.01007391	0.22839090	0.48177961
Linear	1	0.00097941	0.00075599	0.01945704	0.00086979	0.48020950
Quadratic	1	0.00512854	0.01046640	0.00832153	0.10531402	0.32321491
AB vs. CUR	1	0.00582981	0.00441258	0.02925164	0.00039208	0.33531338
Error	15	0.00277406	0.03614749	0.19471185	0.49917621	2.59550718
CV, %		0.84	2.84	5.31	6.30	6.40

Appendix 3 Table 17. Analysis of variance for ADG (Exp. 1)

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	23						
Rep	5	3953.56980	1603.637360	10078.07038	2505.23713	13476.10029	4165.19461
Trt	3	241.34512	163.936577	3369.20495	370.46881	417.64246	324.02928
Linear	1	133.2687113	255.9687734	1650.957387	36.8672456	785.4249097	277.8550010
Quadratic	1	568.7477217	2.5068022	3853.129755	268.4456161	414.9267548	344.4738641
AB vs. CUR	1	478.2851631	223.3054386	2095.622721	29.6164563	901.0627217	299.2525720
Error	15	604.44875	1986.37732	1421.27167	815.69579	3054.7885	1310.53455
CV, %		40.59	19.26	10.90	13.13	8.10	8.30

Appendix 3 Table 18. Analysis of variance for ADFI (Exp. 1)

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	23						
Rep	5	695.652525	3122.54022	7402.05819	567.657167	71628.3598	15648.35690
Trt	3	228.303898	738.69613	1084.41378	196.330920	50833.7493	8529.01306
Linear	1	84.5857004	51.169218	2489.751380	100.6589994	56736.2727	8066.50805
Quadratic	1	431.9995694	1798.958030	183.851980	134.3231402	91396.4042	14030.13181
AB vs. CUR	1	581.0890651	1507.850018	1222.628842	47.7418580	114107.6551	14158.95652
Error	15	252.765892	1422.36839	1857.26408	846.37848	15402.4016	4092.0031
CV, %		8.37	11.36	7.14	7.57	10.48	8.50

Appendix 3 Table 19. Analysis of variance for G:F (Exp. 1)

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	23						
Rep	5	0.11773407	0.01793327	0.01268068	0.01310220	0.00413571	0.00283393
Trt	3	0.00550580	0.00340547	0.00610962	0.00218263	0.00786172	0.00220624
Linear	1	0.00466663	0.00111010	0.00024592	0.00000296	0.00630701	0.00199286
Quadratic	1	0.00956757	0.00881421	0.00902249	0.00341299	0.01551381	0.00415239
AB vs. CUR	1	0.00894809	0.00107221	0.00169270	0.00033829	0.01476360	0.00426156
Error	15	0.01748679	0.00565948	0.00196206	0.00202628	0.00138060	0.00081589
CV, %		42.22	10.79	7.76	7.98	6.38	4.91

Appendix 3 Table 20. Analysis of variance for activity score for LPS challenge (Exp. 1)

		Mean square				
Source	**df**	**H0**	**H3**	**H6**	**H12**	**H24**
Total	23					
Rep	5	0.01041667	0.66666667	0.93541667	1.16000000	0.12388889
Trt	3	0.01041667	0.08333333	0.39930556	0.27089372	0.13985507
Linear	1	0.00029762	0.00476191	0.71458351	0.02508719	0.05540546
Quadratic	1	0.01731602	0.07819259	0.47724327	0.66404647	0.10721043
AB vs. CUR	1	0.00347222	0.00000000	1.00347222	0.60000000	0.03750000
Error	15	0.01041667	0.15000000	0.47430556	0.47797619	0.05932540
CV, %		2.05	18.59	32.73	18.82	5.07

Appendix 3 Table 21. Analysis of variance for % BW loss from h 0 for LPS challenge (Exp. 1)

		Mean square			
Source	**df**	**H3**	**H6**	**H12**	**H24**
Total	23				
Rep	5	3.27320838	0.95502807	22.5817903	21.5304360
Trt	3	3.03522782	1.06725033	9.0486355	5.4030123
Linear	1	3.78841727	0.14939532	13.51438225	3.67007104
Quadratic	1	5.30571981	2.61568211	13.29319295	10.62365219
AB vs. CUR	1	8.21073242	2.39014938	29.52422778	15.20722979
Error	15	0.76809021	0.94827144	5.0663995	4.3244445
CV, %		0.91	1.02	2.35	2.13

Appendix 3 Table 22. Analysis of variance for rectal temperature for LPS challenge (Exp. 1)

		Mean square				
Source	**df**	**H0**	**H3**	**H6**	**H12**	**H24**
Total	23					
Rep	5	0.02929446	1.66177562	0.60250375	0.49894285	0.09621332
Trt	3	0.03502715	0.25192809	0.56161811	0.16274471	0.03047959
Linear	1	0.00026494	0.10411350	0.24716529	0.16095582	0.05002908
Quadratic	1	0.08857051	0.08322023	0.04464343	0.17196984	0.01676645
AB vs. CUR	1	0.01977563	0.43210132	0.33682534	0.17269935	0.01314240
Error	15	0.07086072	0.43438156	0.56750795	0.26082873	0.04527723
CV, %		0.67	1.61	1.86	1.28	0.54

Appendix 3 Table 23. Fixed effects for changes in temperature for LPS challenge (Exp. 1)

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	92	0.63	0.5974
Hr	4	92	40.73	<0.0001
Trt x Hr	12	92	0.72	0.7276

Appendix 3 Table 24. Analysis of variance for TNF-α for LPS challenge (Exp. 1)

		Mean square			Mean square	
Source	**df**	**H0**	**H3**	**df**	**H6**	**H24**
Total	21			20		
Rep	5	2333.26075	167618058.5	5	2698680.43	12472.82255
Trt	3	112.18903	68092144.1	3	801303.61	9118.59053
Linear	1	381.7195471	45042937.5	1	1871686.971	18348.03686
Quadratic	1	41.9286715	128274912.0	1	248697.978	106.60820
AB vs. CUR	1	116.8948516	190425426.7	1	1605110.126	8477.54689
Error	13	357.70561	64060667	14	1388375.52	7793.3278
CV, %		20.67	72.55		48.15	56.34

Appendix 3 Table 25. Fixed effects for changes in TNF-α for LPS challenge (Exp. 1)

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	65	0.62	0.6040
Hr	3	65	23.68	<0.0001
Trt x Hr	9	65	0.70	0.7069

Appendix 3 Table 26. Analysis of variance for CRP for LPS challenge (Exp. 1)

		Mean square			Mean square	
Source	**df**	**H0**	**H3**	**df**	**H6**	**H24**
Total	23			22		
Rep	5	0.23828755	0.26391667	5	0.13935972	0.84968056
Trt	3	0.04070345	0.24291667	3	0.33690368	0.52485809
Linear	1	0.06373052	0.25029756	1	0.04615926	0.26073617
Quadratic	1	0.00174405	0.40941794	1	1.04351332	1.21391043
AB vs. CUR	1	0.07742841	0.00013889	1	0.30741682	0.16016002
Error	15	0.36845576	0.22658333	14	0.21621825	0.82566468
CV, %		64.57	51.93		34.98	32.62

Appendix 3 Table 27. Fixed effects for changes in CRP for LPS challenge (Exp. 1)

Effect	Num df	Den df	F value	Pr > F
Trt	3	73	1.18	0.2261
Hr	3	73	61.70	<0.0001
Trt x Hr	9	73	0.47	0.8919

Appendix 3 Table 28. Analysis of variance for BUN for LPS challenge (Exp. 1)

		Mean square			Mean square	
Source	df	H0	H3	df	H6	H24
Total	23			22		
Rep	5	2.58184156	2.05468750	5	2.92625000	15.32875000
Trt	3	5.22265089	2.32204861	3	2.41582126	19.49873188
Linear	1	4.84239002	2.54650472	1	0.00499167	3.71286448
Quadratic	1	10.27057760	3.27381277	1	7.67219982	44.02074344
AB vs. CUR	1	14.72033608	6.87586806	1	3.56576087	16.64402174
Error	15	1.95829904	2.11163194	14	4.57038690	36.1138393
CV, %		26.13	26.57		30.64	51.72

Appendix 3 Table 29. Fixed effects for changes in BUN for LPS challenge (Exp. 1)

Effect	Num df	Den df	F value	Pr > F
Trt	3	73	0.23	0.8719
Hr	3	73	19.96	<0.0001
Trt x Hr	9	73	0.36	0.9517

Appendix 3 Table 30. Analysis of variance for glucose for LPS challenge (Exp. 1)

		Mean square			Mean square	
Source	**df**	**H0**	**H3**	**df**	**H6**	**H24**
Total	23			22		
Rep	5	246.347891	190.7213542	5	572.356806	625.928889
Trt	3	2.500129	42.5303819	3	92.689161	69.232428
Linear	1	5.95432505	0.58936280	1	93.19339409	17.61806878
Quadratic	1	1.23478407	9.06086571	1	82.10412644	29.65682776
AB vs. CUR	1	4.86835561	4.62586806	1	0.33067633	8.24458031
Error	15	90.906842	77.407465	14	204.885218	152.604861
CV, %		9.14	10.08		21.03	12.54

Appendix 3 Table 31. Fixed effects for changes in glucose for LPS challenge (Exp. 1)

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	73	0.18	0.9113
Hr	3	73	44.29	<0.0001
Trt x Hr	9	73	0.25	0.9855

Appendix 3 Table 32. Analysis of variance for total protein for LPS challenge (Exp. 1)

		Mean square			Mean square	
Source	**df**	**H0**	**H3**	**df**	**H6**	**H24**
Total	23			22		
Rep	5	0.47920943	0.62548437	5	0.60198750	0.51755972
Trt	3	0.03494631	0.02065104	3	0.08320894	0.03002479
Linear	1	0.00706505	0.00488170	1	0.00277393	0.00433425
Quadratic	1	0.03110551	0.02143126	1	0.04450464	0.00236003
AB vs. CUR	1	0.00077428	0.00021701	1	0.00176087	0.00634435
Error	15	0.10197177	0.09815104	14	0.08783780	0.06236855
CV, %		6.63	7.51		7.35	5.66

Appendix 3 Table 33. Fixed effects for changes in total protein for LPS challenge (Exp. 1)

Effect	Num df	Den df	F value	Pr > F
Trt	3	73	0.42	0.7421
Hr	3	73	79.60	<0.0001
Trt x Hr	9	73	0.39	0.9377

Appendix 3 Table 34. Analysis of variance for triglycerides for LPS challenge (Exp. 1)

		Mean square			Mean square	
Source	df	H0	H3	df	H6	H24
Total	23			22		
Rep	5	189.8676505	678.929167	5	106.6737500	234.761389
Trt	3	58.9147269	136.260417	3	100.6279589	40.698007
Linear	1	121.9259629	360.7741018	1	284.7001111	44.83521573
Quadratic	1	51.9586057	31.4612026	1	2.3900711	17.64365987
AB vs. CUR	1	163.7547261	113.7534722	1	257.2521739	0.00037742
Error	15	102.021440	306.387500	14	114.654315	115.745040
CV, %		37.39	38.70		44.21	30.48

Appendix 3 Table 35. Fixed effects for changes in triglycerides for LPS challenge (Exp. 1)

Effect	Num df	Den df	F value	Pr > F
Trt	3	73	2.45	0.0700
Hr	3	73	22.18	<0.0001
Trt x Hr	9	73	0.69	0.7198

Appendix 3 Table 36. Pig means for curcumin intake (Exp. 2)

			Intake, mg/kg of BW/d
Pen	**Rep**	**Trt**	**Curcumin**
9F	1	AB	0.00
10F	2	AB	0.00
12F	3	AB	0.00
2B	4	AB	0.00
4B	5	AB	0.00
5B	6	AB	0.00
14F	7	AB	0.00
1F	1	80	2.75
4F	2	80	2.73
13F	3	80	2.86
9B	4	80	2.57
3B	5	80	3.00
6B	6	80	2.88
7F	7	80	3.22
2F	1	160	5.15
11F	2	160	5.22
5F	3	160	5.78
1B	4	160	5.77
10B	5	160	5.59
13B	6	160	5.01
7B	7	160	6.15
8F	1	320	11.24
3F	2	320	10.37
6F	3	320	10.61
8B	4	320	12.20
11B	5	320	10.34
12B	6	320	12.76
14B	7	320	13.03

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 37. Pen means for BW (Exp. 2)

			BW, kg				
Pen	**Rep**	**Trt**	**D0**	**D7**	**D14**	**D21**	**D42**
9F	1	AB	7.4	9.0	10.9	12.8	25.1
10F	2	AB	6.0	7.6	9.4	10.7	19.1
12F	3	AB	5.6	7.6	10.4	11.5	24.0
2B	4	AB	7.0	8.6	10.9	14.1	25.2
4B	5	AB	6.6	7.7	10.3	13.0	24.3
5B	6	AB	5.2	6.6	9.2	11.6	22.0
14F	7	AB	4.5	6.7	8.8	9.7	19.3
1F	1	80	7.5	8.9	10.3	13.1	23.1
4F	2	80	6.1	7.6	9.7	12.2	20.1
13F	3	80	5.6	7.2	8.7	10.7	19.5
9B	4	80	6.9	8.2	10.6	12.0	22.0
3B	5	80	6.4	7.5	9.9	11.5	20.4
6B	6	80	5.3	6.4	8.9	11.6	20.7
7F	7	80	4.5	6.3	8.0	11.0	21.7
2F	1	160	7.5	9.0	11.3	13.6	23.2
11F	2	160	6.0	7.8	9.4	11.6	21.1
5F	3	160	5.5	7.0	8.6	10.7	20.5
1B	4	160	6.9	8.2	10.2	12.5	23.6
10B	5	160	6.6	8.0	10.0	11.7	22.9
13B	6	160	5.1	6.5	9.0	12.1	18.3
7B	7	160	4.6	6.0	8.3	10.8	21.2
8F	1	320	7.4	9.2	10.8	13.3	23.5
3F	2	320	6.1	7.4	9.2	11.0	19.9
6F	3	320	5.7	7.4	8.9	11.2	18.9
8B	4	320	6.8	7.9	10.1	11.7	22.4
11B	5	320	6.5	7.3	9.0	10.9	20.5
12B	6	320	5.2	6.7	8.5	10.6	20.1
14B	7	320	4.4	6.3	7.8	10.2	18.8

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 38. Pen means for ADG (Exp. 2)

			ADG, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
9F	1	AB	224	311	269	256	723	465
10F	2	AB	236	295	256	226	492	345
12F	3	AB	285	317	398	281	734	483
2B	4	AB	230	309	330	338	654	479
4B	5	AB	168	258	366	309	664	468
5B	6	AB	201	227	366	307	608	442
14F	7	AB	309	369	300	249	566	391
1F	1	80	201	319	207	268	590	412
4F	2	80	222	290	296	290	470	371
13F	3	80	233	279	220	244	519	367
9B	4	80	193	254	342	245	584	397
3B	5	80	159	211	347	244	520	368
6B	6	80	168	233	353	301	534	405
7F	7	80	256	309	240	308	632	453
2F	1	160	207	313	337	292	564	414
11F	2	160	264	300	225	267	559	397
5F	3	160	215	264	225	248	572	393
1B	4	160	180	274	287	267	651	439
10B	5	160	206	282	287	242	660	429
13B	6	160	202	211	355	331	365	347
7B	7	160	209	232	326	297	608	436
8F	1	320	249	324	233	280	602	424
3F	2	320	183	256	264	233	524	363
6F	3	320	254	337	212	263	454	348
8B	4	320	160	306	309	235	630	412
11B	5	320	118	178	248	208	570	370
12B	6	320	209	254	267	259	556	392
14B	7	320	269	282	217	275	506	378

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 39. Pen means for ADFI (Exp. 2)

			ADFI, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
9F	1	AB	311	269	473	446	1100	739
10F	2	AB	295	256	437	430	941	659
12F	3	AB	317	398	492	445	1162	766
2B	4	AB	309	330	470	478	1061	739
4B	5	AB	258	366	492	465	901	660
5B	6	AB	227	366	460	438	986	683
14F	7	AB	369	300	468	456	867	640
1F	1	80	319	207	368	427	1141	746
4F	2	80	290	296	407	427	938	655
13F	3	80	279	220	423	394	938	637
9B	4	80	254	342	460	418	963	662
3B	5	80	211	347	420	482	1015	721
6B	6	80	233	353	449	431	933	656
7F	7	80	309	240	398	435	1060	714
2F	1	160	313	337	531	534	945	718
11F	2	160	300	225	411	398	914	629
5F	3	160	264	225	347	377	994	653
1B	4	160	274	287	457	427	1182	765
10B	5	160	282	287	405	403	1098	714
13B	6	160	211	355	445	427	706	552
7B	7	160	232	326	398	384	1035	675
8F	1	320	324	233	434	431	1204	777
3F	2	320	256	264	364	370	882	599
6F	3	320	337	212	363	410	827	597
8B	4	320	306	309	502	445	1186	776
11B	5	320	178	248	379	336	936	605
12B	6	320	254	267	428	393	1085	703
14B	7	320	282	217	340	390	1011	668

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 40. Pen means for G:F (Exp. 2)

			G:F					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
9F	1	AB	0.719	0.568	0.497	0.657	0.657	0.574
10F	2	AB	0.802	0.585	0.330	0.523	0.523	0.524
12F	3	AB	0.898	0.809	0.302	0.631	0.631	0.630
2B	4	AB	0.743	0.703	0.691	0.616	0.616	0.707
4B	5	AB	0.654	0.743	0.607	0.737	0.737	0.664
5B	6	AB	0.886	0.796	0.563	0.617	0.617	0.700
14F	7	AB	0.838	0.640	0.263	0.652	0.652	0.547
1F	1	80	0.629	0.564	0.667	0.517	0.517	0.628
4F	2	80	0.765	0.729	0.606	0.500	0.500	0.681
13F	3	80	0.837	0.521	0.581	0.553	0.553	0.620
9B	4	80	0.758	0.743	0.371	0.606	0.606	0.586
3B	5	80	0.754	0.826	0.278	0.512	0.512	0.506
6B	6	80	0.722	0.787	0.624	0.572	0.572	0.698
7F	7	80	0.827	0.602	0.717	0.597	0.597	0.708
2F	1	160	0.663	0.634	0.436	0.597	0.597	0.546
11F	2	160	0.881	0.547	0.644	0.611	0.611	0.670
5F	3	160	0.816	0.650	0.586	0.576	0.576	0.659
1B	4	160	0.657	0.628	0.606	0.551	0.551	0.625
10B	5	160	0.730	0.708	0.446	0.601	0.601	0.600
13B	6	160	0.962	0.796	0.701	0.517	0.517	0.777
7B	7	160	0.902	0.817	0.683	0.588	0.588	0.774
8F	1	320	0.770	0.537	0.665	0.499	0.499	0.648
3F	2	320	0.715	0.724	0.515	0.594	0.594	0.630
6F	3	320	0.755	0.585	0.612	0.548	0.548	0.643
8B	4	320	0.524	0.616	0.449	0.531	0.531	0.529
11B	5	320	0.664	0.654	0.573	0.608	0.608	0.620
12B	6	320	0.822	0.625	0.606	0.513	0.513	0.659
14B	7	320	0.954	0.638	0.619	0.500	0.500	0.705

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 41. Pen means for activity score for LPS challenge (Exp. 2)

			Activity Score				
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H12**	**H24**
9F	1	AB	5.0	2.0	3.0	4.0	5.0
10F	2	AB	5.0	3.0	3.0	4.0	5.0
12F	3	AB	5.0	3.0	4.0	4.0	5.0
2B	4	AB	5.0	4.0	4.0	4.0	5.0
4B	5	AB	5.0	3.0	3.0	4.0	5.0
5B	6	AB	5.0	4.0	3.0	4.0	5.0
14F	7	AB	5.0	3.0	3.0	4.0	5.0
1F	1	80	5.0	3.0	4.0	5.0	5.0
4F	2	80	5.0	3.0	3.0	3.0	4.0
13F	3	80	5.0	2.0	3.0	4.0	5.0
9B	4	80	5.0	3.0	3.0	4.0	5.0
3B	5	80	5.0	3.0	3.0	3.0	5.0
6B	6	80	5.0	3.0	3.0	4.0	5.0
7F	7	80	5.0	2.0	3.0	3.0	5.0
2F	1	160	5.0	3.0	4.0	4.0	5.0
11F	2	160	5.0	3.0	2.0	3.0	5.0
5F	3	160	5.0	3.0	3.0	3.0	5.0
1B	4	160	5.0	2.0	3.0	4.0	4.0
10B	5	160	5.0	3.0	3.0	4.0	5.0
13B	6	160	5.0	3.0	3.0	3.0	5.0
7B	7	160	5.0	2.0	3.0	3.0	5.0
8F	1	320	5.0	2.0	3.0	3.0	5.0
3F	2	320	5.0	3.0	4.0	4.0	5.0
6F	3	320	5.0	3.0	4.0	4.0	5.0
8B	4	320	5.0	3.0	3.0	4.0	5.0
11B	5	320	5.0	3.0	3.0	3.0	4.0
12B	6	320	5.0	4.0	3.0	4.0	5.0
14B	7	320	5.0	2.0	3.0	4.0	5.0

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 42. Pen means for % BW loss from h 0 for LPS challenge (Exp. 2)

			% BW loss from h 0			
Pen	**Rep**	**Trt**	**H3**	**H6**	**H12**	**H24**
9F	1	AB	97.2	95.2	93.8	93.8
10F	2	AB	97.4	96.5	94.8	96.5
12F	3	AB	99.2	98.4	100.0	103.2
2B	4	AB	98.4	98.4	98.4	101.6
4B	5	AB	97.5	95.0	92.4	95.8
5B	6	AB	99.2	96.9	96.9	99.2
14F	7	AB	100.0	99.1	98.2	98.2
1F	1	80	97.7	95.3	97.7	98.4
4F	2	80	96.6	94.9	94.0	94.0
13F	3	80	99.1	97.2	97.2	97.2
9B	4	80	98.5	97.0	97.0	95.1
3B	5	80	99.2	99.2	99.2	96.7
6B	6	80	98.2	97.3	94.7	95.6
7F	7	80	97.3	94.6	93.7	94.6
2F	1	160	97.9	96.6	96.6	96.6
11F	2	160	98.9	94.7	94.7	95.8
5F	3	160	100.0	99.0	97.1	100.0
1B	4	160	97.8	96.3	97.0	96.3
10B	5	160	96.2	95.4	96.2	99.2
13B	6	160	100.0	98.0	97.1	98.0
7B	7	160	97.6	96.0	95.2	97.6
8F	1	320	100.8	96.8	97.6	95.2
3F	2	320	96.9	95.8	96.9	96.9
6F	3	320	99.1	97.2	97.2	100.0
8B	4	320	98.3	95.8	96.6	100.0
11B	5	320	98.8	98.8	97.7	97.7
12B	6	320	96.9	95.8	93.8	100.0
14B	7	320	96.2	93.3	93.3	100.0

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 43. Pen means for rectal temperature and changes in rectal temperature for LPS challenge (Exp. 2)

			Rectal Temperature, °C					Changes in Rectal Temperature			
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H12**	**H24**	**H3**	**H6**	**H12**	**H24**
9F	1	AB	39.9	40.7	40.5	40.2	39.2	0.78	0.56	0.33	-0.67
10F	2	AB	39.6	40.9	40.7	40.1	39.2	1.28	1.11	0.50	-0.39
12F	3	AB	39.9	41.5	40.4	40.2	39.5	1.55	0.50	0.28	-0.44
2B	4	AB	39.7	40.8	40.8	41.0	39.7	1.11	1.05	1.22	0.00
4B	5	AB	39.6	41.5	40.6	40.5	39.4	1.94	1.00	0.94	-0.17
5B	6	AB	39.9	41.9	41.1	40.3	39.6	2.00	1.22	0.44	-0.28
14F	7	AB	40.0	40.7	40.6	39.5	39.2	0.67	0.56	-0.50	-0.78
1F	1	80	39.1	41.3	40.7	40.0	39.4	2.22	1.55	0.89	0.28
4F	2	80	39.8	41.1	41.3	40.9	39.6	1.33	1.50	1.11	-0.22
13F	3	80	39.2	40.8	40.9	39.9	39.3	1.61	1.72	0.72	0.11
9B	4	80	40.0	41.6	40.9	40.5	39.4	1.61	0.94	0.56	-0.56
3B	5	80	39.6	41.5	40.6	40.5	39.4	1.94	1.00	0.94	-0.17
6B	6	80	39.6	41.1	40.3	40.0	39.0	1.44	0.72	0.39	-0.67
7F	7	80	40.2	41.3	40.6	39.7	39.3	1.05	0.33	-0.50	-0.94
2F	1	160	39.4	41.4	40.6	40.0	39.3	2.00	1.17	0.56	-0.11
11F	2	160	39.2	40.0	40.3	40.0	39.2	0.72	1.11	0.72	0.00
5F	3	160	39.7	41.3	40.7	40.1	39.7	1.61	0.94	0.39	0.00
1B	4	160	39.2	41.0	40.4	40.3	39.3	1.72	1.17	1.05	0.06
10B	5	160	40.7	41.5	40.1	40.5	39.7	0.83	-0.56	-0.22	-1.00
13B	6	160	39.7	41.6	41.1	40.6	39.2	1.89	1.39	0.94	-0.44
7B	7	160	39.6	41.2	40.6	40.2	39.5	1.55	0.94	0.61	-0.11
8F	1	320	40.0	41.1	40.6	39.7	39.3	1.11	0.61	-0.28	-0.67
3F	2	320	39.1	40.5	40.5	39.6	39.4	1.39	1.33	0.50	0.28
6F	3	320	39.2	41.0	39.9	39.2	38.9	1.78	0.67	0.00	-0.33
8B	4	320	39.4	40.7	40.2	40.2	39.3	1.28	0.78	0.78	-0.11
11B	5	320	40.0	40.7	40.7	40.0	39.5	0.78	0.72	0.00	-0.44
12B	6	320	39.2	41.1	41.0	40.2	39.5	1.89	1.83	1.05	0.33
14B	7	320	39.5	41.0	40.0	39.6	39.3	1.50	0.44	0.06	-0.22

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 44. Pig means for TNF-α and changes in TNF-α for LPS challenge (Exp. 2)

			TNF-α, pg/mL				Changes in TNF-α		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9F	1	AB	58.5	4023	1583	144	3965	1525	85.3
10F	2	AB	103	9300	918	224	9197	814	121
12F	3	AB	126	1677	485	93.4	1551	358	-32.8
2B	4	AB	118	1864	555	113	1747	438	-4.6
4B	5	AB	108	8084	2178	90.9	7976	2071	-16.7
5B	6	AB	90.7	1805	532	76.8	1714	442	-13.9
14F	7	AB	87.4	1658	415	127	1570	328	39.8
1F	1	80	90.1	4253	1388	81.5	4163	1298	-8.6
4F	2	80	110	4969	1936	148	4859	1826	38.5
13F	3	80	81.4	2550	845	114	2469	764	32.4
9B	4	80	138	2674	948	86.8	2536	809	-51.5
3B	5	80	119	2287	903	73.4	2168	784	-45.8
6B	6	80	98.8	1269	1224	104	1170	1126	5.4
7F	7	80	100	5346	1385	122	5246	1285	22.8
2F	1	160	115	3670	1256	125	3555	1141	9.6
11F	2	160	118	5262	546	101	5144	428	-17.3
5F	3	160	124	3645	1052	106	3521	928	-17.8
1B	4	160	103	6149	2063	108	6045	1960	4.6
10B	5	160	85.5	2771	784	100	2686	699	14.3
13B	6	160	60.9	4518	642	78.7	4457	581	17.8
7B	7	160	60.7	1381	901	68.2	1320	841	7.4
8F	1	320	154	9895	3189	244	9742	3036	90.0
3F	2	320	94.9	3589	1846	106	3495	1751	11.1
6F	3	320	115	4151	940	122	4036	825	6.2
8B	4	320	157	7934	2346	150	7777	2188	-7.1
11B	5	320	86.6	2209	867	197	2122	780	110
12B	6	320	121	3364	755	78.7	3243	633	-42.5
14B	7	320	48.5	2687	1074	64.8	2639	1026	16.4

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 45. Pig means for CRP and changes in CRP for LPS challenge (Exp. 2)

			CRP, mg/mL				Changes in CRP		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9F	1	AB	0.40	0.40	0.90	3.55	0.00	0.50	3.15
10F	2	AB	0.25	0.30	0.90	3.95	0.05	0.65	3.70
12F	3	AB	3.50	2.60	2.50	5.40	-0.90	-1.00	1.90
2B	4	AB	0.20	0.40	1.00	5.35	0.20	0.80	5.15
4B	5	AB	1.30	1.40	1.90	2.55	0.10	0.60	1.25
5B	6	AB	5.40	5.40	5.00	6.15	0.00	-0.40	0.75
14F	7	AB	1.20	1.10	1.50	1.00	-0.10	0.30	-0.20
1F	1	80	0.20	0.20	0.50	2.05	0.00	0.30	1.85
4F	2	80	0.60	0.40	1.20	5.10	-0.20	0.60	4.50
13F	3	80	0.30	0.30	0.50	2.55	0.00	0.20	2.25
9B	4	80	0.90	1.20	1.40	4.35	0.30	0.50	3.45
3B	5	80	0.30	0.30	0.50	4.10	0.00	0.20	3.80
6B	6	80	0.90	1.00	1.50	2.20	0.10	0.60	1.30
7F	7	80	0.90	1.10	1.50	3.00	0.20	0.60	2.10
2F	1	160	0.30	0.20	0.70	2.30	-0.10	0.40	2.00
11F	2	160	0.20	0.20	0.40	3.90	0.00	0.20	3.70
5F	3	160	0.80	0.90	1.60	5.55	0.10	0.80	4.75
1B	4	160	0.60	0.60	1.00	2.55	0.00	0.40	1.95
10B	5	160	1.75	2.30	2.50	2.45	0.55	0.75	0.70
13B	6	160	0.30	0.30	0.80	1.80	0.00	0.50	1.50
7B	7	160	0.75	0.60	1.40	2.35	-0.15	0.65	1.60
8F	1	320	0.40	0.50	0.60	1.70	0.10	0.20	1.30
3F	2	320	0.10	0.20	0.40	1.20	0.10	0.30	1.10
6F	3	320	1.20	1.10	1.30	3.40	-0.10	0.10	2.20
8B	4	320	0.40	0.40	0.70	1.55	0.00	0.30	1.15
11B	5	320	0.10	0.10	0.50	4.35	0.00	0.40	4.25
12B	6	320	0.10	0.10	0.50	5.00	0.00	0.40	4.90
14B	7	320	0.25	0.40	0.90	1.20	0.15	0.65	0.95

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 46. Pig means for BUN and changes in BUN for LPS challenge (Exp. 2)

			BUN, mg/d				Changes in BUN		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9F	1	AB	6.0	6.0	6.0	12.0	0.0	0.0	6.0
10F	2	AB	4.0	5.0	5.0	14.0	1.0	1.0	10.0
12F	3	AB	6.0	6.5	8.0	9.0	0.5	2.0	3.0
2B	4	AB	11.5	11.0	11.5	10.0	-0.5	0.0	-1.5
4B	5	AB	2.0	3.0	4.0	8.0	1.0	2.0	6.0
5B	6	AB	4.0	4.0	4.0	6.0	0.0	0.0	2.0
14F	7	AB	12.0	11.5	13.0	24.0	-0.5	1.0	12.0
1F	1	80	3.0	3.0	3.0	7.0	0.0	0.0	4.0
4F	2	80	2.0	2.0	3.0	7.0	0.0	1.0	5.0
13F	3	80	7.0	7.0	8.0	12.0	0.0	1.0	5.0
9B	4	80	10.0	10.0	13.0	20.0	0.0	3.0	10.0
3B	5	80	15.5	15.0	17.5	13.5	-0.5	2.0	-2.0
6B	6	80	3.0	3.0	2.5	5.5	0.0	-0.5	2.5
7F	7	80	7.0	8.0	8.0	9.0	1.0	1.0	2.0
2F	1	160	3.0	3.0	3.0	8.0	0.0	0.0	5.0
11F	2	160	19.0	18.0	20.0	18.0	-1.0	1.0	-1.0
5F	3	160	5.0	4.0	4.0	8.0	-1.0	-1.0	3.0
1B	4	160	6.0	6.0	7.0	9.5	0.0	1.0	3.5
10B	5	160	5.0	7.0	10.5	10.0	2.0	5.5	5.0
13B	6	160	3.0	2.0	3.0	8.0	-1.0	0.0	5.0
7B	7	160	3.0	3.0	4.0	6.5	0.0	1.0	3.5
8F	1	320	11.0	12.0	14.5	15.0	1.0	3.5	4.0
3F	2	320	8.5	8.0	8.0	11.0	-0.5	-0.5	2.5
6F	3	320	12.0	13.0	14.5	11.5	1.0	2.5	-0.5
8B	4	320	10.0	10.0	11.5	19.0	0.0	1.5	9.0
11B	5	320	13.5	14.0	13.0	16.0	0.5	-0.5	2.5
12B	6	320	14.5	11.0	9.0	10.0	-3.5	-5.5	-4.5
14B	7	320	3.0	3.0	6.0	7.0	0.0	3.0	4.0

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 47. Pig means for glucose and changes in glucose for LPS challenge (Exp. 2)

			Glucose, mg/dL				Changes in Glucose		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9F	1	AB	120	108	84	87	-11.5	-36.0	-32.5
10F	2	AB	118	108	82	73	-10.5	-36.5	-45.5
12F	3	AB	114	93	94	100	-21.5	-20.0	-14.0
2B	4	AB	98	98	85	98	0.5	-12.5	0.0
4B	5	AB	95	66	53	79	-29.5	-42.5	-16.5
5B	6	AB	106	106	84	111	0.5	-21.5	5.5
14F	7	AB	64	62	61	58	-2.0	-3.0	-6.5
1F	1	80	126	118	86	88	-8.5	-40.5	-38.5
4F	2	80	110	95	67	88	-15.5	-43.5	-22.0
13F	3	80	90	92	69	83	2.5	-21.0	-7.0
9B	4	80	92	81	66	79	-11.0	-26.0	-13.0
3B	5	80	86	91	72	83	4.5	-14.5	-3.0
6B	6	80	108	121	83	99	12.5	-25.0	-9.5
7F	7	80	105	92	77	90	-13.5	-28.0	-15.0
2F	1	160	97	108	87	88	11.0	-9.5	-8.5
11F	2	160	87	88	75	87	1.0	-12.0	0.0
5F	3	160	121	104	86	108	-17.0	-35.5	-13.0
1B	4	160	106	94	79	75	-12.5	-27.0	-31.5
10B	5	160	95	80	73	79	-15.0	-22.5	-16.5
13B	6	160	124	105	64	103	-18.5	-59.5	-20.5
7B	7	160	108	106	90	97	-2.0	-18.5	-11.0
8F	1	320	96	74	67	65	-22.5	-29.0	-31.5
3F	2	320	115	93	75	90	-22.5	-40.5	-25.5
6F	3	320	91	77	78	83	-13.5	-13.0	-8.0
8B	4	320	105	114	75	52	9.0	-30.0	-53.5
11B	5	320	92	104	97	84	12.5	5.5	-7.5
12B	6	320	104	80	72	81	-24.5	-32.0	-23.5
14B	7	320	113	89	97	112	-24.0	-16.5	-1.0

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 48. Pig means for total protein and changes in total protein for LPS challenge (Exp. 2)

			Total Protein, g/dL				Changes in Total Protein		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9F	1	AB	4.2	3.0	2.8	3.8	-1.2	-1.4	-0.4
10F	2	AB	5.0	3.2	3.1	4.3	-1.8	-1.9	-0.7
12F	3	AB	5.6	4.8	4.8	5.3	-0.8	-0.8	-0.3
2B	4	AB	5.2	4.7	4.7	4.5	-0.5	-0.5	-0.7
4B	5	AB	4.9	4.6	4.1	4.5	-0.4	-0.9	-0.5
5B	6	AB	5.6	5.3	4.9	5.4	-0.3	-0.8	-0.3
14F	7	AB	4.5	3.9	3.8	4.1	-0.6	-0.7	-0.4
1F	1	80	4.7	3.6	3.4	4.1	-1.1	-1.3	-0.6
4F	2	80	5.1	3.6	3.5	4.7	-1.5	-1.7	-0.5
13F	3	80	4.0	3.5	3.5	3.7	-0.5	-0.5	-0.3
9B	4	80	4.9	4.7	4.5	4.8	-0.2	-0.4	-0.1
3B	5	80	5.3	4.6	4.4	4.9	-0.8	-1.0	-0.4
6B	6	80	5.1	4.2	3.8	4.7	-0.9	-1.4	-0.5
7F	7	80	4.9	4.6	4.1	4.7	-0.3	-0.8	-0.2
2F	1	160	4.5	3.7	3.3	4.3	-0.8	-1.3	-0.3
11F	2	160	4.5	3.4	3.3	4.0	-1.1	-1.2	-0.5
5F	3	160	6.0	4.9	4.6	5.1	-1.1	-1.4	-0.9
1B	4	160	4.5	3.4	3.6	4.2	-1.2	-0.9	-0.3
10B	5	160	5.5	4.9	4.6	5.1	-0.6	-0.9	-0.5
13B	6	160	4.6	3.5	3.5	4.2	-1.1	-1.2	-0.5
7B	7	160	4.4	3.0	3.1	4.1	-1.5	-1.3	-0.4
8F	1	320	5.8	4.3	4.2	5.1	-1.5	-1.6	-0.7
3F	2	320	4.6	3.5	3.3	3.9	-1.2	-1.3	-0.7
6F	3	320	4.7	4.2	3.9	4.4	-0.5	-0.8	-0.3
8B	4	320	5.3	4.4	4.7	4.5	-0.9	-0.6	-0.8
11B	5	320	5.2	4.7	4.3	5.1	-0.6	-1.0	-0.2
12B	6	320	4.8	4.0	3.6	4.2	-0.9	-1.3	-0.6
14B	7	320	4.2	3.5	3.6	3.8	-0.8	-0.6	-0.4

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 49. Pig means for triglycerides and changes in triglycerides for LPS challenge (Exp. 2)

			Triglycerides, mg/mL				Changes in Triglycerides		
Pen	**Rep**	**Trt**	**H0**	**H3**	**H6**	**H24**	**H3**	**H6**	**H24**
9F	1	AB	32	48	26	19	15.5	-6.0	-13.0
10F	2	AB	60	90	46	32	29.5	-14.5	-28.5
12F	3	AB	31	48	22	43	17.0	-9.0	11.5
2B	4	AB	53	57	40	42	3.5	-13.5	-11.5
4B	5	AB	19	32	24	26	13.0	4.5	7.0
5B	6	AB	44	42	19	53	-2.0	-25.0	8.5
14F	7	AB	27	33	20	59	6.5	-6.5	32.0
1F	1	80	23	24	11	12	0.5	-12.5	-11.5
4F	2	80	44	35	14	23	-9.5	-30.5	-21.0
13F	3	80	32	39	10	17	7.5	-21.5	-14.5
9B	4	80	27	27	13	27	0.5	-14.0	0.5
3B	5	80	18	26	17	21	8.0	-1.5	2.5
6B	6	80	67	79	33	61	12.5	-34.0	-5.5
7F	7	80	26	40	13	24	13.5	-13.0	-2.0
2F	1	160	35	35	16	29	0.0	-19.5	-6.0
11F	2	160	46	34	19	28	-12.0	-27.0	-18.0
5F	3	160	112	103	32	41	-9.5	-80.5	-71.0
1B	4	160	25	29	9	17	4.0	-16.0	-7.5
10B	5	160	29	37	39	33	8.0	10.0	4.0
13B	6	160	21	22	12	40	1.0	-9.5	19.0
7B	7	160	16	28	12	27	11.5	-4.0	11.0
8F	1	320	40	41	20	21	1.0	-20.0	-19.0
3F	2	320	30	25	9	25	-4.5	-20.5	-4.5
6F	3	320	36	34	17	38	-1.5	-18.5	2.5
8B	4	320	25	25	14	15	0.5	-10.5	-9.5
11B	5	320	81	73	30	23	-8.0	-51.0	-58.0
12B	6	320	12	15	15	16	3.0	3.0	4.0
14B	7	320	11	23	15	17	12.0	4.0	5.5

AB = 55 mg/kg of carbadox
80 = 80 mg/kg of curcumin powder
160 = 160 mg/kg of curcumin powder
320 = 320 mg/kg of curcumin powder

Appendix 3 Table 50. Analysis of variance for curcumin intake (Exp. 2)

		Mean square
Source	**df**	**Curcumin**
Total	27	
Rep	6	0.4865901
Trt	3	168.4997204
Linear	1	505.2376460
Quadratic	1	0.1647458
AB vs. CUR	1	230.8397953
Error	18	0.3477195
CV, %		11.86

Appendix 3 Table 51. Analysis of variance for BW (Exp. 2)

		Mean square				
Source	**df**	**D0**	**D7**	**D14**	**D21**	**D42**
Total	27					
Rep	6	4.18611709	3.42279580	3.26663689	3.54279926	9.57284724
Trt	3	0.00097941	0.08419234	0.70989307	0.60720217	5.74209600
Linear	1	0.00083949	0.11689098	1.64935576	1.40259498	11.58038328
Quadratic	1	0.00042929	0.05481560	0.10269325	0.17458765	1.34784794
AB vs. CUR	1	0.00039176	0.23038118	1.66157130	0.49024865	14.17988928
Error	18	0.00459301	0.04436768	0.14040014	0.44196181	1.8140202
CV, %		1.12	2.80	3.92	5.68	6.27

Appendix 3 Table 52. Analysis of variance for ADG (Exp. 2)

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	27						
Rep	6	4654.71513	3990.74286	5603.11156	1192.945236	8924.42912	1836.99141
Trt	3	1511.33602	6833.49249	3874.15713	1283.598749	11427.61648	3903.67563
Linear	1	1998.335574	18124.05360	203.92017	3026.770885	17033.07808	7883.674507
Quadratic	1	1325.443845	152.10130	11124.06368	357.601911	8625.00515	967.02624
AB vs. CUR	1	4321.886351	13358.04681	7076.22069	1049.712415	32515.34047	9716.908036
Error	18	864.88322	2240.84278	7804.6135	935.39729	4924.5879	1206.65596
CV, %		13.70	16.40	28.77	11.32	12.20	8.54

Appendix 3 Table 53. Analysis of variance for ADFI (Exp. 2)

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	27						
Rep	6	4506.96194	3021.23542	5866.57721	1516.80494	21019.0436	7052.55344
Trt	3	1309.05211	6073.70196	10981.10923	3594.39226	1591.7069	944.86147
Linear	1	979.832333	12745.30762	26934.37630	10561.97092	950.136083	1849.424924
Quadratic	1	2734.384110	1945.02075	4208.22091	110.41075	3120.407653	948.463374
AB vs. CUR	1	3631.585074	15743.60415	3118.61403	6484.58195	43.034541	2250.219457
Error	18	1124.46582	1607.34047	6042.0961	1213.3773	13844.2262	2781.99470
CV, %		12.05	9.34	13.71	8.20	11.76	7.73

Appendix 3 Table 54. Analysis of variance for G:F (Exp. 2)

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	27						
Rep	6	0.02806083	0.01384735	0.00892791	0.00740890	0.00163130	0.00096019
Trt	3	0.00540529	0.00644209	0.02138049	0.00241668	0.01183925	0.00482009
Linear	1	0.00503045	0.01664198	0.03859155	0.00074231	0.01996196	0.00728569
Quadratic	1	0.00147937	0.00211430	0.02532146	0.00496828	0.00468558	0.00024069
AB vs. CUR	1	0.00312918	0.00436420	0.05897007	0.00265878	0.03081368	0.00920016
Error	18	0.00575917	0.00746397	0.02065120	0.00447161	0.00243184	0.00187034
CV, %		9.82	12.88	26.41	10.48	8.56	7.25

Appendix 3 Table 55. Analysis of variance for activity score for LPS challenge (Exp. 2)

		Mean square				
Source	**df**	**H0**	**H3**	**H6**	**H12**	**H24**
Total	27					
Rep	6	0.0	0.40476190	0.22619048	0.11904762	0.07142857
Trt	3	0.0	0.28571429	0.13095238	0.38095238	0.03571429
Linear	1	0.0	0.14693893	0.00102040	0.26122461	0.05000003
Quadratic	1	0.0	0.62708755	0.37105747	0.83487980	0.04545460
AB vs. CUR	1	0.0	0.76190476	0.10714286	0.76190476	0.10714286
Error	18	0.0	0.34126984	0.24206349	0.32539683	0.11904762
CV, %		0.0	20.45	15.48	15.36	7.05

Appendix 3 Table 56. Analysis of variance for % BW loss from h 0 for LPS challenge (Exp. 2)

		Mean square			
Source	**df**	**H3**	**H6**	**H12**	**H24**
Total	27				
Rep	6	1.41274264	3.23141327	4.69286023	8.74280618
Trt	3	0.19303280	0.87262175	0.06062268	9.63520230
Linear	1	0.12995930	2.07331853	0.13127315	3.44171424
Quadratic	1	0.01455193	0.17285691	0.00534150	11.78167307
AB vs. CUR	1	0.29438918	2.11937283	0.13349849	4.79641909
Error	18	1.72924577	2.42222729	3.84621129	3.6552974
CV, %		1.34	1.61	2.04	1.96

Appendix 3 Table 57. Analysis of variance for rectal temperature for LPS challenge (Exp. 2)

		Mean square				
Source	**df**	**H0**	**H3**	**H6**	**H12**	**H24**
Total	27					
Rep	6	0.16697722	0.21902611	0.11586282	0.39805864	0.04291282
Trt	3	0.12859831	0.32614122	0.07361750	0.12143093	0.03786342
Linear	1	0.45705027	0.80710738	0.13404883	0.34768605	0.03691387
Quadratic	1	0.00087797	0.23462377	0.00010520	0.04573454	0.01565576
AB vs. CUR	1	0.26332750	0.04656386	0.01594410	0.07309438	0.00027909
Error	18	0.12598480	0.13407936	0.11565355	0.13159935	0.08229868
CV, %		0.90	0.89	0.84	0.90	0.73

Appendix 3 Table 58. Fixed effects for changes in temperature for LPS challenge (Exp. 2)

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	129	0.38	0.7690
Hr	4	129	137.57	<0.0001
Trt x Hr	12	129	1.06	0.3976

Appendix 3 Table 59. Analysis of variance for TNF-α for LPS challenge (Exp. 2)

		Mean square			
Source	**df**	**H0**	**H3**	**H6**	**H24**
Total	27				
Rep	6	1149.424019	6563396.65	592978.824	2226.39898
Trt	3	340.979037	2663359.14	535440.781	2290.49849
Linear	1	387.4980847	4043065.098	1169327.553	1160.240159
Quadratic	1	175.7155130	2854842.649	79906.114	5703.059116
AB vs. CUR	1	141.4949814	5198.372	565440.028	623.692551
Error	18	636.16620	5863180.5	374940.85	1816.94396
CV, %		24.57	60.01	51.09	36.74

Appendix 3 Table 60. Fixed effects for changes in TNF-α for LPS challenge (Exp. 2)

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	90	0.60	0.6144
Hr	3	90	69.01	<0.0001
Trt x Hr	9	90	0.48	0.8824

Appendix 3 Table 61. Analysis of variance for CRP for LPS challenge (Exp. 2)

		Mean square			
Source	**df**	**H0**	**H3**	**H6**	**H24**
Total	27				
Rep	6	1.16247024	1.02809524	0.80392857	2.63488095
Trt	3	2.67738095	2.12666667	1.99845238	2.36690476
Linear	1	5.05730821	4.23200164	4.27152189	6.40065396
Quadratic	1	1.83696988	1.22909335	0.57053973	0.67876128
AB vs. CUR	1	7.68047618	5.97333333	5.10107143	5.35047619
Error	18	1.08953373	1.06888889	0.72789683	2.09773810
CV, %		123.84	120.62	70.05	44.76

Appendix 3 Table 62. Fixed effects for changes in CRP for LPS challenge (Exp. 2)

Effect	Num df	Den df	F value	Pr > F
Trt	3	90	0.26	0.8506
Hr	3	90	58.36	<0.0001
Trt x Hr	9	90	0.18	0.9956

Appendix 3 Table 63. Analysis of variance for BUN for LPS challenge (Exp. 2)

		Mean square			
Source	df	H0	H3	H6	H24
Total	27				
Rep	6	8.69642857	12.30654762	21.2500000	20.2172619
Trt	3	26.00892857	22.98809524	20.6755952	12.9375000
Linear	1	56.59208646	44.57244396	46.94923197	5.07167992
Quadratic	1	17.92297330	20.31907855	11.42917542	32.96125728
AB vs. CUR	1	9.00297619	5.25000000	9.66964286	3.64583333
Error	18	25.5297619	21.5922619	24.6825397	24.0347222
CV, %		67.53	62.25	59.32	43.65

Appendix 3 Table 64. Fixed effects for changes in BUN for LPS challenge (Exp. 2)

Effect	Num df	Den df	F value	Pr > F
Trt	3	90	0.40	0.7528
Hr	3	90	20.40	<0.0001
Trt x Hr	9	90	0.66	0.7392

Appendix 3 Table 65. Analysis of variance for glucose for LPS challenge (Exp. 2)

		Mean square			
Source	**df**	**H0**	**H3**	**H6**	**H24**
Total	27				
Rep	6	185.247024	185.830357	46.1428571	243.955357
Trt	3	17.500000	127.747024	47.1279762	123.916667
Linear	1	0.80000030	36.6430634	60.50226010	115.8867117
Quadratic	1	34.37499845	331.7290424	8.54915023	206.2264037
AB vs. CUR	1	9.33333333	81.0297857	0.36011905	0.1071429
Error	18	222.3263689	252.691468	154.301587	216.229167
CV, %		14.49	16.86	16.02	17.06

Appendix 3 Table 66. Fixed effects for changes in glucose for LPS challenge (Exp. 2)

Effect	**Num df**	**Den df**	**F value**	**Pr > F**
Trt	3	90	0.08	0.9700
Hr	3	90	29.79	<0.0001
Trt x Hr	9	90	1.04	0.4131

Appendix 3 Table 67. Analysis of variance for total protein for LPS challenge (Exp. 2)

		Mean square			
Source	**df**	**H0**	**H3**	**H6**	**H24**
Total	27				
Rep	6	0.23559524	0.83270833	0.77369048	0.26226190
Trt	3	0.03976190	0.18508929	0.12508929	0.02880952
Linear	1	0.00146939	0.08173726	0.01757400	0.05587755
Quadratic	1	0.07937154	0.33841383	0.32961276	0.01962897
AB vs. CUR	1	0.05761905	0.20502976	0.16741071	0.04761905
Error	18	0.29309524	0.34120040	0.24710317	0.25075397
CV, %		11.06	14.47	12.86	11.23

Appendix 3 Table 68. Fixed effects for changes in total protein for LPS challenge (Exp. 2)

Effect	Num df	Den df	F value	Pr > F
Trt	3	90	0.96	0.4137
Hr	3	90	99.53	<0.0001
Trt x Hr	9	90	0.60	0.7931

Appendix 3 Table 69. Analysis of variance for triglycerides for LPS challenge (Exp. 2)

		Mean square			
Source	df	H0	H3	H6	H24
Total	27				
Rep	6	425.321429	276.747024	57.8482143	216.639881
Trt	3	84.000000	319.413690	213.3928571	357.488095
Linear	1	33.06124610	710.6025222	232.1726180	732.0502589
Quadratic	1	31.40625699	59.6126999	178.3696808	43.6820178
AB vs. CUR	1	23.04761905	771.0744048	581.4404762	810.9642857
Error	18	574.41667	533.10813	94.538690	125.425595
CV, %		65.92	56.74	48.53	38.01

Appendix 3 Table 70. Fixed effects for changes in triglycerides for LPS challenge (Exp. 2)

Effect	Num df	Den df	F value	Pr > F
Trt	3	90	0.71	0.5468
Hr	3	90	25.76	<0.0001
Trt x Hr	9	90	0.62	0.7770

APPENDIX 4

EXPERIMENT 4

Appendix 4 Table 1. Pig means for curcumin intake

			Intake, mg/kg of BW/d
Pen	Rep	Trt	Curcumin
7	1	AB	0.00
22	2	AB	0.00
25	3	AB	0.00
21	1	20	0.34
23	2	20	0.34
12	3	20	0.34
8	1	40	0.64
9	2	40	0.66
11	3	40	0.77
20	1	80	1.32
10	2	80	1.34
24	3	80	1.36

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 4 Table 2. Pen means for BW

			BW, kg					
Pen	Rep	Trt	D0	D28	D42	D63	D91	D126
7	1	AB	27.0	48.8	62.4	80.5	101.6	118.6
22	2	AB	24.0	46.0	58.0	76.6	95.0	114.7
25	3	AB	21.6	42.4	54.0	73.7	94.6	113.8
21	1	20	26.7	49.9	64.2	83.2	100.2	118.4
23	2	20	22.2	45.6	59.4	78.5	102.7	127.0
12	3	20	21.8	43.8	56.7	78.0	97.7	116.1
8	1	40	27.6	50.6	63.0	82.3	101.6	118.6
9	2	40	23.5	46.5	59.2	78.0	95.7	116.8
11	3	40	21.1	43.5	58.3	79.8	100.9	123.1
20	1	80	26.1	51.0	62.6	81.9	101.8	113.2
10	2	80	23.7	45.6	57.1	77.1	93.7	116.6
24	3	80	23.2	45.1	58.7	78.0	100.5	120.9

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 4 Table 3. Pen means for ADG

			ADG, g					
Pen	**Rep**	**Trt**	**D0-28**	**D28-42**	**D42-63**	**D63-91**	**D91-126**	**D0-126**
7	1	AB	0.78	1.78	0.97	2.27	0.82	1.80
22	2	AB	0.79	1.71	0.86	2.37	0.85	1.97
25	3	AB	0.74	1.37	0.83	1.91	0.90	1.75
21	1	20	0.83	1.71	1.02	2.28	0.87	2.03
23	2	20	0.84	1.69	0.99	2.25	0.87	1.95
12	3	20	0.78	1.51	0.92	2.26	0.97	2.02
8	1	40	0.82	1.67	0.89	2.15	0.88	1.60
9	2	40	0.82	1.95	0.91	1.82	0.86	1.79
11	3	40	0.80	1.61	1.05	2.28	0.98	2.56
20	1	80	0.89	1.74	0.83	2.03	0.88	1.89
10	2	80	0.78	1.64	0.83	2.07	0.91	1.75
24	3	80	0.78	1.46	0.97	2.06	0.88	1.97

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 4 Table 4. Pen means for ADFI

			ADFI, g					
Pen	**Rep**	**Trt**	**D0-28**	**D28-42**	**D42-63**	**D63-91**	**D91-126**	**D0-126**
7	1	AB	1.78	0.97	2.27	0.82	1.80	0.84
22	2	AB	1.71	0.86	2.37	0.85	1.97	0.73
25	3	AB	1.37	0.83	1.91	0.90	1.75	0.83
21	1	20	1.71	1.02	2.28	0.87	2.03	0.68
23	2	20	1.69	0.99	2.25	0.87	1.95	0.97
12	3	20	1.51	0.92	2.26	0.97	2.02	0.79
8	1	40	1.67	0.89	2.15	0.88	1.60	0.77
9	2	40	1.95	0.91	1.82	0.86	1.79	0.71
11	3	40	1.61	1.05	2.28	0.98	2.56	0.84
20	1	80	1.74	0.83	2.03	0.88	1.89	0.80
10	2	80	1.64	0.83	2.07	0.91	1.75	0.66
24	3	80	1.46	0.97	2.06	0.88	1.97	0.90

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 4 Table 5. Pen means for G:F

			G:F					
Pen	**Rep**	**Trt**	**D0-28**	**D28-42**	**D42-63**	**D63-91**	**D91-126**	**D0-126**
7	1	AB	0.44	0.43	0.46	0.33	0.26	0.37
22	2	AB	0.46	0.36	0.43	0.28	0.23	0.33
25	3	AB	0.54	0.43	0.51	0.34	0.32	0.41
21	1	20	0.49	0.45	0.43	0.28	0.27	0.36
23	2	20	0.49	0.44	0.44	0.35	0.32	0.39
12	3	20	0.52	0.41	0.48	0.32	0.32	0.40
8	1	40	0.49	0.41	0.55	0.31	0.26	0.38
9	2	40	0.42	0.50	0.48	0.30	0.30	0.37
11	3	40	0.50	0.46	0.38	0.30	0.30	0.37
20	1	80	0.51	0.41	0.46	0.30	0.19	0.36
10	2	80	0.48	0.40	0.52	0.28	0.30	0.37
24	3	80	0.54	0.47	0.44	0.33	0.32	0.40

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 4 Table 6 Pen means for carcass data

Pen	**Rep**	**Trt**	**HCW, kg**	**DP, %**	**BF, mm**	**LMA, mm^2**	**Initial FFL, kg**	**Final FFL, kg**	**FFL gn, kg**	**FFL, %**
7	1	AB	90.7	76.5	22.2	5355	9.1	47.6	0.33	52.3
22	2	AB	88.3	76.9	21.0	5258	8.0	46.7	0.31	52.8
25	3	AB	89.0	78.2	20.3	5177	7.0	47.0	0.34	52.8
21	1	20	98.2	79.0	21.6	5097	9.4	50.2	0.35	51.1
23	2	20	99.0	77.9	24.1	5403	7.2	50.5	0.35	51.0
12	3	20	90.5	77.9	20.3	5161	7.1	47.6	0.34	52.6
8	1	40	91.5	77.2	22.9	5097	9.4	47.0	0.32	51.4
9	2	40	89.5	76.6	22.2	5145	7.8	46.5	0.31	52.0
11	3	40	93.4	75.8	24.1	4597	6.8	46.1	0.33	49.5
20	1	80	88.3	78.1	20.3	4968	8.8	46.2	0.32	52.3
10	2	80	91.4	78.4	19.7	6194	7.8	50.8	0.34	55.6
24	3	80	92.3	76.4	22.9	4968	7.6	47.0	0.33	51.0

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 4 Table 7 Pen means for sensory characteristic data

			Juiciness		Tenderness			
Pen	Rep	Trt	Initial	Sustained	Initial	Sustained	Pork flavor	Off-flavor
7	1	AB	5.5	5.5	5.5	5.5	5.5	1.5
22	2	AB	6.3	6.2	6.3	6.2	6.2	1.0
25	3	AB	5.3	5.0	6.0	5.8	6.3	1.0
21	1	20	5.8	5.7	5.8	5.7	5.3	1.0
23	2	20	5.2	5.0	6.2	6.0	5.3	1.3
12	3	20	6.2	6.2	6.0	5.8	6.2	1.0
8	1	40	4.8	4.5	5.7	5.5	5.8	1.0
9	2	40	6.0	5.8	6.2	6.2	6.2	1.2
11	3	40	6.5	6.3	6.8	6.5	5.8	1.0
20	1	80	5.7	5.2	5.8	5.7	6.0	1.2
10	2	80	5.3	5.0	6.2	6.0	5.7	1.0
24	3	80	5.2	5.0	5.7	5.5	5.2	1.2

AB = 55 mg/kg of carbadox
20 = 20 mg/kg of curcumin powder
40 = 40 mg/kg of curcumin powder
80 = 80 mg/kg of curcumin powder

Appendix 4 Table 8. Analysis of variance for curcumin intake

		Mean square
Source	df	Curcumin
Total	11	
Rep	2	0.00187295
Trt	3	0.98107435
Linear	1	2.94249153
Quadratic	1	0.00057720
AB vs. CUR	1	1.40035180
Error	6	0.00105712
CV, %		5.50

Appendix 4 Table 9. Analysis of variance for BW

		Mean square					
Source	**df**	**D0**	**D28**	**D42**	**D63**	**D91**	**D126**
Total	11						
Rep	2	25.42617702	41.55075989	40.60807997	27.11061749	21.08603583	2.86660394
Trt	3	0.35186242	1.26833298	2.67806795	6.10599493	5.46754353	14.84292382
Linear	1	0.17032981	3.45535080	1.50841176	3.41434101	1.08175795	0.00195867
Quadratic	1	0.34653659	0.34902634	5.88757922	13.55601193	10.76469748	37.05378019
AB vs. CUR	1	0.11827776	2.76519443	7.20007496	16.35263999	12.62048449	23.40131484
Error	6	0.75378686	0.56989286	1.8553655	1.31546698	10.0481110	20.7089639
CV, %		3.61	1.62	2.29	1.45	3.21	3.85

Appendix 4 Table 10. Analysis of variance for ADG

		Mean square					
Source	**df**	**D0-28**	**D28-42**	**D42-63**	**D63-91**	**D91-126**	**D0-126**
Total	11						
Rep	2	0.00267036	0.00244852	0.00581650	0.00660904	0.02102587	0.00386736
Trt	3	0.00172553	0.00742572	0.00144011	0.00093925	0.00349854	0.00125552
Linear	1	0.00266753	0.00202939	0.00079324	0.00104385	0.00182605	0.00001153
Quadratic	1	0.00177439	0.01719187	0.00325634	0.00025714	0.00858654	0.00303779
AB vs. CUR	1	0.00513681	0.00531241	0.00382455	0.00038621	0.00116779	0.00179989
Error	6	0.00090408	0.00696662	0.00127190	0.01239538	0.00702995	0.00150658
CV, %		3.74	9.05	4.02	14.01	13.59	4.96

Appendix 4 Table 11. Analysis of variance for ADFI

		Mean square					
Source	**df**	**D0-28**	**D28-42**	**D42-63**	**D63-91**	**D91-126**	**D0-126**
Total	11						
Rep	2	0.08239617	0.00398497	0.06932734	0.01611732	0.00614818	0.00013146
Trt	3	0.01118237	0.02682411	0.01948639	0.00248804	0.01806300	0.00334446
Linear	1	0.00000016	0.04841230	0.00004080	0.00559921	0.02498973	0.00267867
Quadratic	1	0.02384013	0.00045156	0.05300281	0.00099473	0.00281390	0.00674981
AB vs. CUR	1	0.00466450	0.00604434	0.02886473	0.00162550	0.01615180	0.00010066
Error	6	0.01020624	0.03730815	0.07272080	0.03786556	0.04470293	0.02321310
CV, %		6.11	8.99	14.02	7.60	9.63	7.29

Appendix 4 Table 12. Analysis of variance for G:F

		Mean square					
Source	**df**	**D0-28**	**D28-42**	**D42-63**	**D63-91**	**D91-126**	**D0-126**
Total	11						
Rep	2	0.00390105	0.00049073	0.00034786	0.00031633	0.00535467	0.00093788
Trt	3	0.00095029	0.00131447	0.00034658	0.00020404	0.00062711	0.00013395
Linear	1	0.00079885	0.00042851	0.00035110	0.00052100	0.00002711	0.00003076
Quadratic	1	0.00042873	0.00331538	0.00016390	0.00000670	0.00118581	0.00010564
AB vs. CUR	1	0.00036591	0.00220708	0.00000964	0.00020287	0.00075141	0.00025169
Error	6	0.00074394	0.00163533	0.00353584	0.00092098	0.00115401	0.00050474
CV, %		5.58	9.39	12.77	9.80	12.06	5.99

Appendix 4 Table 13. Analysis of variance for carcass data

		Mean square							
Source	**df**	**HCW**	**DP**	**BF**	**LMA**	**Initial FFL**	**Final FFL**	**FFL gn**	**FFL, %**
Total	11								
Rep	2	0.89018979	0.38916301	0.03360208	290581.5640	4.50401151	2.93909526	0.00013761	2.11850378
Trt	3	24.08975684	1.64668738	2.77777222	99924.4471	0.01461947	4.75834884	0.00033839	2.63246094
Linear	1	0.67040078	0.00172195	0.13824833	14689.4951	0.01012381	0.00848368	0.00000041	0.39697021
Quadratic	1	25.91048657	0.19830462	7.54868464	208836.9368	0.02350946	0.00318267	0.00000342	7.37859627
AB vs. CUR	1	24.88674986	0.16055626	1.61290000	15290.7239	0.00416444	1.81458362	0.00012707	1.49715326
Error	6	10.3127041	0.81134776	2.81137431	112151.245	0.15291775	2.06373037	0.00013222	1.99435697
CV, %		3.50	1.16	7.69	6.44	4.88	3.01	3.48	2.71

Appendix 4 Table 14. Analysis of variance for sensory characteristic data

		Mean square					
Source	**df**	**Initial Juiciness**	**Sustained Juiciness**	**Initial Tenderness**	**Sustained Tenderness**	**Pork Flavor**	**Off-flavor**
Total	11						
Rep	2	0.12037037	0.18287037	0.28703704	0.25925926	0.04861111	0.01620370
Trt	3	0.09490741	0.20370370	0.06404321	0.05864198	0.13194444	0.00617284
Linear	1	0.00535714	0.01693122	0.03498674	0.01296294	0.13392864	0.00952380
Quadratic	1	0.11640210	0.37524050	0.00150312	0.00000000	0.00727509	0.00487012
AB vs. CUR	1	0.01929012	0.11111111	0.00077160	0.00308642	0.13040123	0.00000000
Error	6	0.40740741	0.46990741	0.10802469	0.06790123	0.19675926	0.04089506
CV, %		11.29	12.59	5.47	4.45	7.66	18.20

APPENDIX 5

EXPERIMENT 5

Appendix 5 Table 1. Pen means for BW

			BW, kg				
Pen	**Rep**	**Trt**	**D0**	**D7**	**D14**	**D21**	**D42**
1	1	CNT	7.5	8.3	10.4	13.0	25.5
11	2	CNT	6.9	7.5	9.5	11.8	23.3
6	3	CNT	5.5	6.4	8.5	10.8	21.8
2	4	CNT	7.3	7.9	9.6	12.4	25.1
3	5	CNT	5.9	6.7	7.8	10.5	23.2
5	6	CNT	4.7	5.7	7.2	10.2	21.6
2	1	CC	7.4	8.1	10.3	12.8	25.3
4	2	CC	6.7	7.7	10.1	13.1	25.2
5	3	CC	5.8	6.3	8.2	10.6	21.2
8	4	CC	7.3	8.0	9.3	12.4	27.1
4	5	CC	5.8	6.3	7.4	10.3	21.0
13	6	CC	4.7	5.6	7.4	10.3	22.3
9	1	SBM	7.5	7.7	9.3	12.2	24.4
10	2	SBM	6.8	7.2	8.9	11.7	22.9
12	3	SBM	6.0	6.2	7.6	9.8	21.0
1	4	SBM	7.3	7.7	8.6	11.5	24.0
11	5	SBM	5.8	6.3	7.1	9.3	20.9
12	6	SBM	4.7	5.5	6.7	9.6	20.9
8	1	SC	7.5	7.9	10.0	12.7	24.0
3	2	SC	6.7	7.0	9.0	12.1	23.8
13	3	SC	5.8	6.2	7.8	9.9	19.9
9	4	SC	7.4	7.5	8.5	11.5	24.9
10	5	SC	5.9	6.5	7.6	10.9	24.6
6	6	SC	4.8	5.4	6.5	9.5	20.9

CNT = control diet
CC = control diet + 80 mg/kg of curcumin powder
SBM = 30% soybean meal diet
SC = 30% soybean diet diet + 80 mg/kg of curcumin powder

Appendix 5 Table 2. Pen means for ADG

			ADG, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
1	1	CNT	110	148	265	251	624	429
11	2	CNT	86	207	254	222	575	390
6	3	CNT	126	203	262	239	551	388
2	4	CNT	83	166	241	243	603	423
3	5	CNT	115	161	170	221	606	414
5	6	CNT	141	168	220	262	543	402
2	1	CC	96	175	285	245	625	426
4	2	CC	141	177	310	291	606	441
5	3	CC	81	211	228	222	526	367
8	4	CC	107	176	175	243	699	471
4	5	CC	79	166	154	218	521	370
13	6	CC	130	202	254	267	571	419
9	1	SBM	26	144	198	213	613	404
10	2	SBM	66	159	208	225	557	383
12	3	SBM	28	151	183	172	527	341
1	4	SBM	57	155	112	195	592	394
11	5	SBM	66	148	107	163	555	359
12	6	SBM	115	153	165	233	537	385
8	1	SC	50	174	261	233	567	393
3	2	SC	47	167	250	222	584	394
13	3	SC	57	178	191	187	499	336
9	4	SC	16	139	147	197	637	417
10	5	SC	86	190	160	242	650	446
6	6	SC	94	163	152	228	560	394

CNT = control diet
CC = control diet + 80 mg/kg of curcumin powder
SBM = 30% soybean meal diet
SC = 30% soybean diet diet + 80 mg/kg of curcumin powder

Appendix 5 Table 3. Pen means for ADFI

			ADFI, g					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
1	1	CNT	148	265	405	404	1083	727
11	2	CNT	207	254	373	378	940	646
6	3	CNT	203	262	387	429	928	666
2	4	CNT	166	241	312	370	1034	702
3	5	CNT	161	170	249	309	1052	681
5	6	CNT	168	220	301	359	1041	700
2	1	CC	175	285	417	419	1118	752
4	2	CC	177	310	370	430	1093	729
5	3	CC	211	228	453	419	897	646
8	4	CC	176	175	267	365	1194	779
4	5	CC	166	154	279	317	875	599
13	6	CC	202	254	304	366	994	680
9	1	SBM	144	198	408	402	1037	704
10	2	SBM	159	208	346	369	988	663
12	3	SBM	151	183	412	363	871	588
1	4	SBM	155	112	229	312	907	598
11	5	SBM	148	107	241	302	963	632
12	6	SBM	153	165	245	325	857	591
8	1	SC	174	261	460	456	1127	775
3	2	SC	167	250	379	390	1034	682
13	3	SC	178	191	301	329	859	581
9	4	SC	139	147	241	317	1025	671
10	5	SC	190	160	300	376	1247	811
6	6	SC	163	152	250	314	1013	660

CNT = control diet
CC = control diet + 80 mg/kg of curcumin powder
SBM = 30% soybean meal diet
SC = 30% soybean diet diet + 80 mg/kg of curcumin powder

Appendix 5 Table 4. Pen means for G:F

			G:F					
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
1	1	CNT	0.743	0.654	0.571	0.621	0.576	0.621
11	2	CNT	0.416	0.679	0.582	0.588	0.611	0.588
6	3	CNT	0.622	0.678	0.464	0.558	0.594	0.558
2	4	CNT	0.498	0.774	0.644	0.659	0.583	0.659
3	5	CNT	0.714	0.684	0.729	0.714	0.576	0.714
5	6	CNT	0.841	0.731	0.698	0.729	0.521	0.729
2	1	CC	0.546	0.684	0.522	0.584	0.559	0.584
4	2	CC	0.795	0.839	0.533	0.678	0.554	0.678
5	3	CC	0.385	0.504	0.606	0.530	0.586	0.530
8	4	CC	0.608	0.655	0.685	0.665	0.586	0.665
4	5	CC	0.478	0.551	0.811	0.689	0.595	0.689
13	6	CC	0.640	0.837	0.704	0.729	0.575	0.729
9	1	SBM	0.180	0.486	0.639	0.530	0.592	0.530
10	2	SBM	0.418	0.602	0.664	0.609	0.564	0.609
12	3	SBM	0.183	0.444	0.583	0.473	0.604	0.473
1	4	SBM	0.370	0.488	0.716	0.625	0.653	0.625
11	5	SBM	0.448	0.444	0.609	0.539	0.576	0.539
12	6	SBM	0.751	0.673	0.725	0.716	0.627	0.716
8	1	SC	0.288	0.567	0.526	0.512	0.504	0.512
3	2	SC	0.282	0.660	0.553	0.569	0.565	0.569
13	3	SC	0.318	0.635	0.608	0.567	0.582	0.567
9	4	SC	0.116	0.611	0.747	0.620	0.622	0.620
10	5	SC	0.453	0.534	0.754	0.645	0.521	0.645
6	6	SC	0.577	0.608	0.804	0.727	0.552	0.727

CNT = control diet
CC = control diet + 80 mg/kg of curcumin powder
SBM = 30% soybean meal diet
SC = 30% soybean diet diet + 80 mg/kg of curcumin powder

Appendix 5 Table 5. Pen means for fecal score

			Fecal Score			
Pen	**Rep**	**Trt**	**D0-7**	**D7-14**	**D14-21**	**D0-21**
1	1	CNT	3.3	3.1	2.5	3.0
11	2	CNT	2.8	2.9	2.6	2.8
6	3	CNT	2.6	2.6	2.8	2.6
2	4	CNT	2.3	3.4	2.6	2.7
3	5	CNT	2.3	3.5	2.4	2.7
5	6	CNT	3.2	2.9	2.4	2.8
2	1	CC	2.9	3.1	2.6	2.9
4	2	CC	3.3	3.2	2.4	3.0
5	3	CC	3.2	2.6	2.1	2.6
8	4	CC	2.3	3.6	2.8	2.9
4	5	CC	2.6	2.6	2.7	2.6
13	6	CC	2.7	3.1	2.9	2.9
9	1	SBM	3.5	3.3	2.9	3.2
10	2	SBM	2.8	3.3	3.1	3.1
12	3	SBM	3.2	3.4	2.5	3.0
1	4	SBM	2.9	4.1	2.6	3.2
11	5	SBM	2.8	3.1	2.9	3.0
12	6	SBM	2.8	3.2	2.7	2.9
8	1	SC	3.3	3.1	2.4	3.0
3	2	SC	2.9	2.8	2.6	2.8
13	3	SC	2.8	3.4	3.1	3.1
9	4	SC	3.7	3.0	2.7	3.1
10	5	SC	2.8	3.4	2.4	2.9
6	6	SC	3.2	3.5	3.3	3.3

CNT = control diet
CC = control diet + 80 mg/kg of curcumin powder
SBM = 30% soybean meal diet
SC = 30% soybean diet diet + 80 mg/kg of curcumin powder

Appendix 5 Table 6. Analysis of variance for BW

		Mean square				
Source	**df**	**D0**	**D7**	**D14**	**D21**	**D42**
Total	23					
Rep	5	4.51140043	3.62348512	5.57983606	5.67600366	12.74285638
Trt	3	0.00836271	0.15915356	0.99948574	0.99149184	2.02966536
SBM	1	0.02333133	0.46769913	2.88059791	2.36658231	4.55881102
CUR	1	0.00173539	0.00878540	0.02961399	0.48251144	1.28750838
SBM x CUR	1	0.00002142	0.00097616	0.08824532	0.12538178	0.24267668
Error	15	0.00965247	0.01907133	0.06280163	0.14724354	1.09407767
CV, %		1.56	2.00	2.96	3.43	4.53

Appendix 5 Table 7. Analysis of variance for ADG

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	23						
Rep	5	1544.16852	7626.01761	5571.00059	1165.135633	5807.75453	2119.86206
Trt	3	4784.84208	7471.11409	1427.33921	2812.220456	828.64550	1633.56159
SBM	1	14284.73253	19447.22445	41.260761	7239.396980	1192.212287	3613.173099
CUR	1	55.33763	1387.61614	4174.761052	1038.079875	1083.998869	1098.822148
SBM x CUR	1	14.45610	1578.50168	65.995804	159.184512	209.725353	188.689523
Error	15	493.72460	614.93905	1436.18207	384.83849	1310.21392	571.48769
CV, %		26.63	12.01	9.76	8.67	6.24	5.99

Appendix 5 Table 8. Analysis of variance for ADFI

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	23						
Rep	5	421.544292	19860.00895	9461.36055	5428.96584	14534.51197	6103.14268
Trt	3	1154.620763	1464.30358	3664.93629	1802.99654	19125.27643	6316.40603
SBM	1	2378.151684	3849.661212	578.678384	4017.190902	4282.78546	5073.869577
CUR	1	996.924455	538.143046	4994.215863	1316.841327	24843.85014	9094.164812
SBM x CUR	1	88.786150	5.106468	216.914610	74.957377	14479.90031	4781.183689
Error	15	258.746909	1320.2788	4298.3962	899.67301	7633.1795	2846.39913
CV, %		9.46	11.00	10.79	8.16	8.67	7.87

Appendix 5 Table 9. Analysis of variance for G:F

		Mean square					
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**	**D21-42**	**D0-42**
Total	23						
Rep	5	0.05605400	0.01768148	0.02694145	0.01878685	0.00152223	0.00205277
Trt	3	0.12352796	0.03868266	0.00288874	0.00585065	0.00206085	0.00100589
SBM	1	0.35022859	0.09571832	0.00591715	0.01573100	0.00008383	0.00042254
CUR	1	0.02018111	0.00497344	0.00217279	0.00098421	0.00321071	0.00107755
SBM x CUR	1	0.00017417	0.01535622	0.00057628	0.00083674	0.00288800	0.00151757
Error	15	0.01965289	0.00493946	0.00390428	0.00145825	0.00085019	0.00066191
CV, %		28.83	11.23	9.69	6.16	5.04	4.36

Appendix 5 Table 10. Analysis of variance for fecal score

		Mean square			
Source	**df**	**D0-7**	**D7-14**	**D14-21**	**D0-21**
Total	23				
Rep	5	0.16904630	0.13730402	0.02848980	0.02807550
Trt	3	0.17643519	0.51356226	0.08006803	0.12091879
SBM	1	0.46296296	0.39995549	0.23431973	0.35876106
CUR	1	0.06337963	0.08610026	0.00013605	0.00010007
SBM x CUR	1	0.00296296	0.02750651	0.00574830	0.00389523
Error	15	0.11325000	0.11172473	0.08227211	0.01981065
CV, %		11.51	10.54	10.74	4.82

VITA

Megan René Bible

Candidate for the Degree of

Doctor of Philosophy

Thesis: INFLUENCE OF CURCUMIN ON GROWTH PERFORMANCE AND IMMUNE STATUS OF NURSERY PIGS

Major Field: Animal Science

Biographical:

Personal:

Born in Okmulgee, OK, September, 22, 1981. Daughter of Dennis Stuckey, Jr. and Lisa Mitchell. Married to Josh Bible on May 17, 2003. Mother of Jayden Bible, born in Stillwater, OK, September 10, 2003 and Wyatt Bible, born in Stillwater, OK, December 31, 2004.

Education:

Completed the requirements for the Doctor of Philosophy in Animal Science at Oklahoma State University, Stillwater, Oklahoma in December, 2013.

Completed the requirements for the Master of Science in Food Science at Oklahoma State University, Stillwater, Oklahoma in May, 2009.

Completed the requirements for the Bachelor of Science in Animal Science at Oklahoma State University, Stillwater, Oklahoma in May, 2005.

Experience:

Research Assistant/Teaching Assistant at Oklahoma State University, 2005-2013.

Professional Memberships:

American Society of Animal Society, Sigma Xi: The Scientific Research Society